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FINAL REPORT for COOPERATIVE AGREEMENT
#INT-87226-COA
with MONTANA STATE UNIVERSITY
FS Contact: L. Jack Lyon
Co-op Contact: Dr. Don Collins

DETERMINATION of MATURATION in GRIZZLY POPULATIONS in MONTANA and YELLOWSTONE NATIONAL PARK

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Dr. Don Collins and Dan Gustafson

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Submitted, February, 1989

DETERMINATION OF MATURATION IN GRIZZLY POPULATIONS IN MONTANA AND YELLOWSTONE NATIONAL PARK

Introduction

The impact of closing the Yellowstone National Park (YNP) garbage dumps on the grizzly bear has been a major source of controversy for over 15 years. Phasing out the dumps occurred between 1968 and 1971 and resulted in the loss of a major concentration of high protein food which has been available to the bears since the 1920's.

The closures were blamed for a major decline in grizzly numbers in Yellowstone from an observed high of 245 in 1967 to a computer predicted low of 136 in 1974 (Craighead et al. 1974). Although the minimum population figure generated by the Craighead model is arguable, most researchers feel a substantial decline in grizzly numbers has occurred since the dump closures.

Reasons for the decline involve both an increase in mortality due to control actions and a significant decline in reproductive and survival rates (Knight and Eberhardt 1984; Knight and Eberhardt 1985). Of particular interest is the distinct difference reported for the age of first reproduction between the 1959-1970 period and the 1974-1982 period (Knight and Eberhardt 1985). During 1959-1970 nearly 70% of the grizzly females observed gave birth at age five. By 1974-1982 the peak had shifted with 58% of the first pregnancies occurring at age 6 and only 17% at age 5 (Knight and Eberhardt 1985). As the earlier time span (1959-70) was largely prior to the dump

closures, it appears that the closure has had a major impact on grizzly maturation in Yellowstone. As maturation is directly correlated with nutritional condition, later maturation would seem to indicate that the dump closures have had an adverse impact on the nutritional status of the Yellowstone grizzly.

To test this hypothesis, an attempt was made to see if maturation could be determined from skeletal tissue. Such a technique, if feasible, would allow direct comparisons of nutritional trends for the entire Yellowstone population and not just the segment represented by females at first reproduction.

Bone tissue arises in two different environments either by intramembranous ossification, which occurs within layer (membrane) of condensed mesenchymal tissue, or by endochondral ossification, which takes place within hyaline cartilage whose shape resembles a small version or model of the bone to be formed. The latter ossification process is primarily responsible for the formation of short and long bones.

Long bones become longer as a result of cell divisions in the epiphyseal plates. When the cartilage of the epiphyseal plate stops growing, it is replaced by bony tissue through the process of ossification. Longitudinal growth of the bone is then no longer possible.

During growth, bone is sensitive to several nutritional and hormonal factors. Insufficient dietary protein causes a deficiency of amino acids and vitamin C necessary for the synthesis of collagen by fibroblasts and osteoblasts. Deficiency

of calcium leads to incomplete calcification of the organic bone matrix. Calcium deficiency may be due either to the lack of calcium in the diet or to the lack of vitamin D which is important for the absorption of calcium by the small intestine.

Major changes in the nutritional quality of a habitat (such as dump closures in YNP) should result in changes in bone growth and maturation. Therefore bones collected from a potentially impacted population during the period of nutritional change should reveal differences in bone maturation. For the Yellowstone grizzly this would involve comparing bone specimens collected prior to the 1968-1971 dump closure period with bone specimens taken from individuals born after 1971.

Geographic variation in skeletal characteristics within a single species may reflect differences in habitat suitability. The Yellowstone grizzly population is well isolated from other grizzly populations in Montana (Knight and Eberhardt, 1984). Examination of skeletal material collected from Northwest Montana during the same time period should serve both as a partial control and as an indicator of comparative habitat suitability.

Method

The skeletons and supporting data: Montana Department of Fish, Wildlife and Parks (MDFWP) has an extensive collection of grizzly skeletons dating back to 1961. The collection consists of 117 specimens from both the Yellowstone area and from Northwest Montana and is presently housed in the Region Three headquarters building at Bozeman. Data is available as to sex,

age, location and a variety of morphological measurements. Skeletal measurements were made primarily by Mr. Kenneth Greer of MDFWP and recorded on a standardized data sheet.

The collection date was taken as the date of death unless otherwise indicated. Age was constructed using the tooth age determination and adding the fraction of the year passed between February 15 (the presumptive date of birth)and the collection date. Year of death was similarly constructed adding that fraction of the year passed from January 1 to the collection date. Location was coded to distinguish Yellowstone area bears from those from Northwest Montana. Condition was coded as one to four corresponding to 'excellent' to 'very poor'. Quantitative measurements pertinent to the study were retained in the original measurement units. All molar measurements refer to the last upper molar.

The new measurements: To meet the objectives of this study, six measurements were made directly of samples taken from the right femur of each skeleton. Measurements included femur length, femur outer circumference, femur inner circumference, femur inner area, femur outer area and sample (slice weight). Unfortunately, widths of epiphyseal plates could not be measured due to the manner in which the skeletons were treated at the time of their original collection. Dermestid beetles had been used to remove the soft tissue and in the process had totally consumed the cartilaginous plates. As all bears were originally collected between 1968 and 1984, histological analysis of the ossified

epiphyseal plates from mature bears was likewise not possible because of the age and condition of the bones. Histological examination of two fresh femura collected in October, 1987 indicated that epiphyseal plate studies would have to be conducted within one to three days of death unless specially treated to avoid tissue deterioration (i.e. formalin fixation).

Each femur was measured for overall length. A cross section of bone was then removed from the center extending toward the proximal end and polished to a uniform width of 5 mm as measured by a dial caliper. The sections were then grouped by age and radiographed. Radiographs were taken using a Collimex Westinghouse X-ray Unit and Kodak Direct Exposure Film (DEF-2) with a setting of 300 mA, 30 K.V.P. and distance of 90cm from target to film. The best exposure time was found to be 2 seconds.

Perimeters and areas of the femur and the medullar cavity were obtained by digitizing tracing of the radiographs using a Jandel Scientific digitizer and Sigma Scan Measurement System. Reproductibility was well within one percent. The polished sections were weighed on an analytical balance to the nearest milligram. Bone density and percentage occupied by the medullar cavity were then calculated from the thickness, areas and weights of the cross sections.

Chemical analysis was conducted to determine percent calcium, phosphorous and magnesium. A one gram sample (the spur) from the first lumbar vertebrae was removed and analyzed using a

modified A.O.A.C. method (Williams, 1984). Bone tissue was dried under vacuum at 100 degrees for 24 hours to a constant weight and placed in individual covered platinum crucibles were then placed in a thermoline type 1400 muffle furnace with a quartz liner and ashed at 600 degrees for 16 hours. After cooling the ashed samples were weighed. Bone tissue was dissolved with nitric acid and reashed. The sample was then dissolved with hydrochloric acid and brought to a final volume with deionized water. Phosphorous was determined by a colorimetric method using a Technicon Auto Analyzer. Calcium and magnesium were determined by Atomic Absorption Spectro Photometry (Schachter, 1959).

Statistical considerations: The data under consideration were not obtained as a random sample from some infinitely large population. This makes ordinary statistical inference technically improper. However, if we concede that the data set is of interest in its own right, normal statistical methods are appropriate for addressing questions concerning non-random organization in the data set itself. Any inferences made from this data concerning larger populations should be made cautiously. This applies to both positive and negative results. The main consideration is how well the bears whose skeletons were saved represent the average bear of that time and place. With regard to sex and age the answer is probably not very well. With regard to other variables we have no reason to believe them not to be representative.

The preliminary analysis reported here focused on

summarizing the overall structure of the data and described the relationships betweeen the variables, especially ragarding size and age. The analysis is largely descriptive relying heavily on linear correlation and graphical analysis. Emphasis is given to aspects of the data structure which confound analyzes addressing some of the more important questions.

Results and Discussion

One bear collected in 1961 was excluded from this analysis because it predated the remaining bears by seven years or more. This left 116 bears collected between 1968 and 1984 with some 41 variables available for comparisons. Seldom, however, was a record complete for all variables. A number of additional variables were available in the MDFWP records, but not utilized either because of lack of pertinence or more commonly because of small sample size. The sample size, mean, standard deviation, minimum and maximum for all variables across the entire sample are given in Table 1.

Data structure: The data is highly structured, with the two sexes, two populations, age structure exceeding 25 years, and a time span of 16 years which, in Yellowstone, includes age and time dependent accessibility to the dumps. Analysis of this data must take full account of this structure. Males and bears from the Yellowstone area are better represented in the sample than females or bears from Northwest Montana, but there is no difference between the two areas as to the composition by sex

(Table 2, P > 0.50, Fisher's exact test). Table 3 presents a comparison of males and females with regard to all variables. This comparison is not overly (significantly) confounded by area, age or year of death and so is relatively easily interpreted. Males are significantly larger than females with regards to most morphological measures and tend to be larger with regards to all the rest. The medullar cavity is only very slightly larger than in females in spite of the males much larger femur. As a result the percent of the femur which is open is significantly less in males than in females. Males tend to have a smaller percentage of calcium, magnesium and phosphorus in the bone, though this tendency is significant only for calcium. Males have a very weak tendency to receive better condition scores than females. The sex differences in size are pronounced, so all analyses will treat the sexes separately or control for size.

Table 1. Summary statistics for all variables across the entire sample, where N is the number of non-missing observations and STD is the sample standard deviation.

Variable	N	Mean	STD	Minimum	Maximum
Sex (M=1, F=2)	116	1.431	.495	1.000	2.000
Area (1=NMT, 2=YNP)	116	1.569	.495	1.000	2.000
Age (years)	116	7.566	6.250	.266	25.258
Year of death	116	77.094	4.385	68.655	84.726
Skull length (in)	94	12.375	2.007	6.000	15.940
Skull width (in)	98	6.848	1.271	3.440	9.500
Body length (in)	74	66.672	13.919	27.500	87.000
Chest girth (in)	60	42.363	10.944	14.000	62.000
Whole weight (lb)	88	279.290	161.724	11.000	790.000
Femur outer area (mm^2)	116	82.229	17.971	31.000	115.500
Femur outer circum. (mm)	116	548.216	215.230	74.400	1019.700
Femur inner area (mm^2)	116	38.338	8.401	15.100	55.700
Femur inner circum. (mm)	116	116.798	48.127	17.000	241.500
Femur length (cm)	116	32.659	6.928	12.100	42.900
Femur slice wt. (g)	116	4.052	1.796	.343	8.633
Percent calcium	112	17.506	2.681	11.500	24.600
Percent magnesium	112	.208	.053	.170	.450
Percent phosphorous	112	7.749	1.164	4.600	10.100
Femur density (g/cm^3)	116	17.456	4.487	4.314	26.360
Percent femur open	116	47.051	5.520	34.735	59.336

Table 2. Breakdown of the 116 bears in the data set by location and sex.

	Males	Females	Totals
Yellowstone area	38	28	66
Northwest Montana	28	22	50
Totals	66	50	116

While the Yellowstone and Northwest Montana segments of the data set do not differ in sex ratio they do differ in age structure (Figure 1). Only 16 percent of the bears from Northwest Montana are older than 10 years, while 36 percent of the bears from the Yellowstone area are older than 10 ($P < 0.05$, Fisher's exact test). Whether this reflects differences in the source populations or in the conditions resulting in collection is unknown. In any case, comparisons between the two locations are impossible without first accounting for age structure.

The temporal structure of the data introduces possible confounding effects with weather and populations size. That is, a few years of unfavorable weather and/or high population density could conceivably cause poor nutrition as easily as closure of the dumps. Bears from two populations, as represented in the data set, show no major differences in occurrence over time (Figure 2) and do not differ significantly overall (Chi-square contingency table, $P > .05$). The Northwest Montana ppopulation however, makes at best a poor control for climatic trends in Yellowstone and can not serve as a control for population size. Climate can probably be addressed with existing data, but population size presents greater difficulty.

Table 3. Comparisons of male and female bears combined from both populations for all variables. The degrees of freedom (df) is corrected to allow for unequal variance, but the associated probability (P) is not corrected for multiple tests. No asterix indicates probabilities greater than 0.05 while one, two and three asterices indicated probabilities less than 0.05, 0.01 and 0.001 respectively.

Variable	Mean Males	Mean Females	T	df	P
Area (1=NMT, 2=YNP)	1.576	1.560	.172	105	.863
Age (years)	7.172	8.086	-.768	98	.444
Year of death	77.386	76.709	.825	105	.411
Skull of length (in)	12.996	11.537	3.729	84	.000***
Skull width (in)	7.147	6.449	2.846	93	.005**
Body length (in)	69.724	61.038	2.640	49	.011*
Chest girth (in)	44.228	37.647	2.023	25	.54
Whole weight (lb)	321.698	197.300	4.229	83	.000***
Femur outer area (mm^2)	86.161	77.038	2.836	110	.005**
Femur outer circum. (mm)	599.561	480.442	3.186	114	.002**
Femur inner area (mm^2)	38.659	37.914	.466	99	.642
Femur inner circum. (mm)	117.645	115.680	.217	103	.829
Femur length (cm)	34.470	30.268	3.371	103	.001**
Femur slice wt. (g)	4.549	3.395	3.787	113	.000***
Percent calcium	17.028	18.144	-2.211	98	.029*
Percent magnesium	.272	.290	-1.743	84	.085
Percent phosphorous	7.600	7.948	-1.554	94	.124
Femur density (g/cm^3)	18.220	16.447	2.130	102	.036*
Percent femur open	45.342	49.307	-4.153	110	.000***

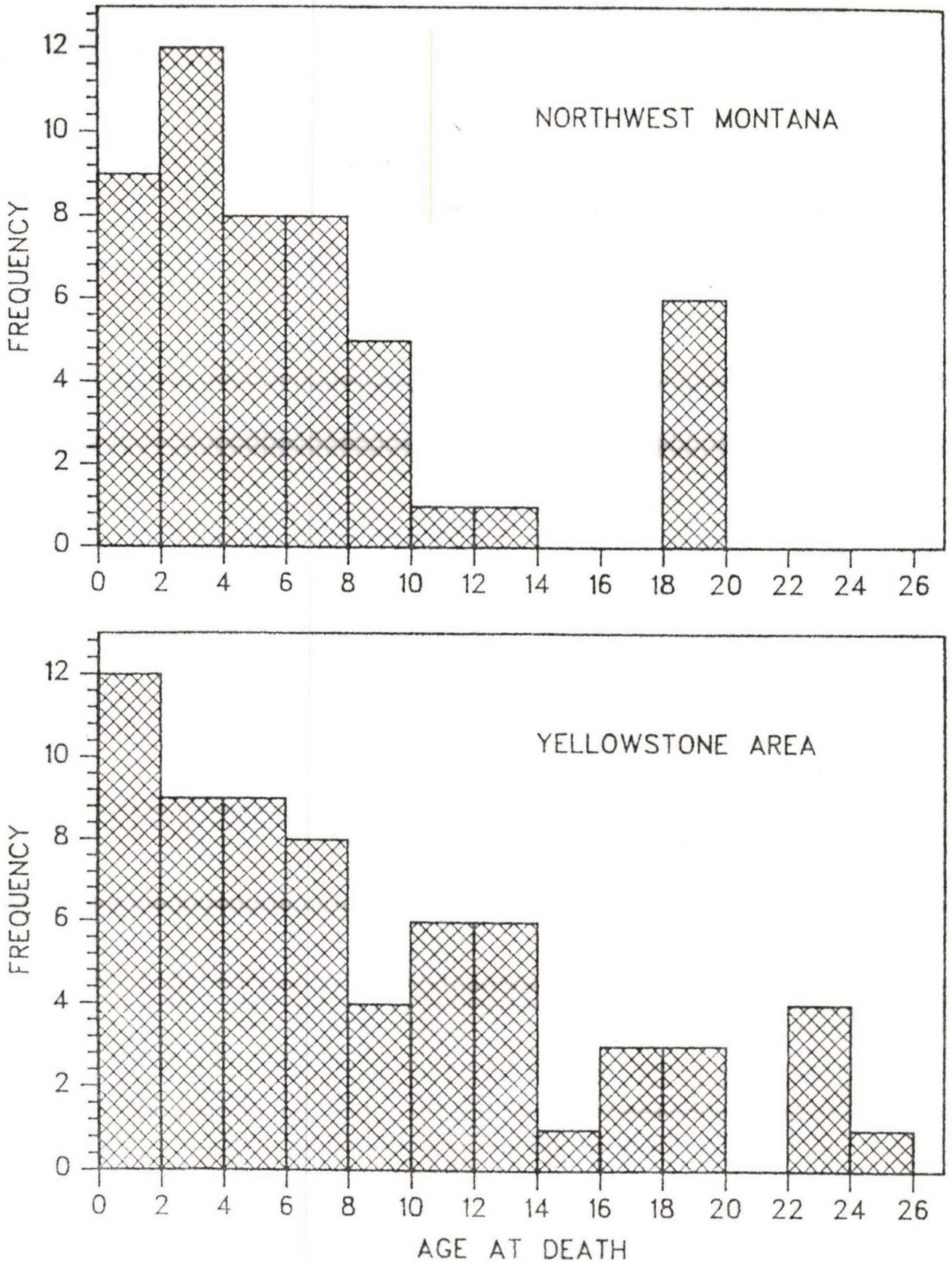

Figure 1. Frequency histograms of age at death for the two grizzly populations.

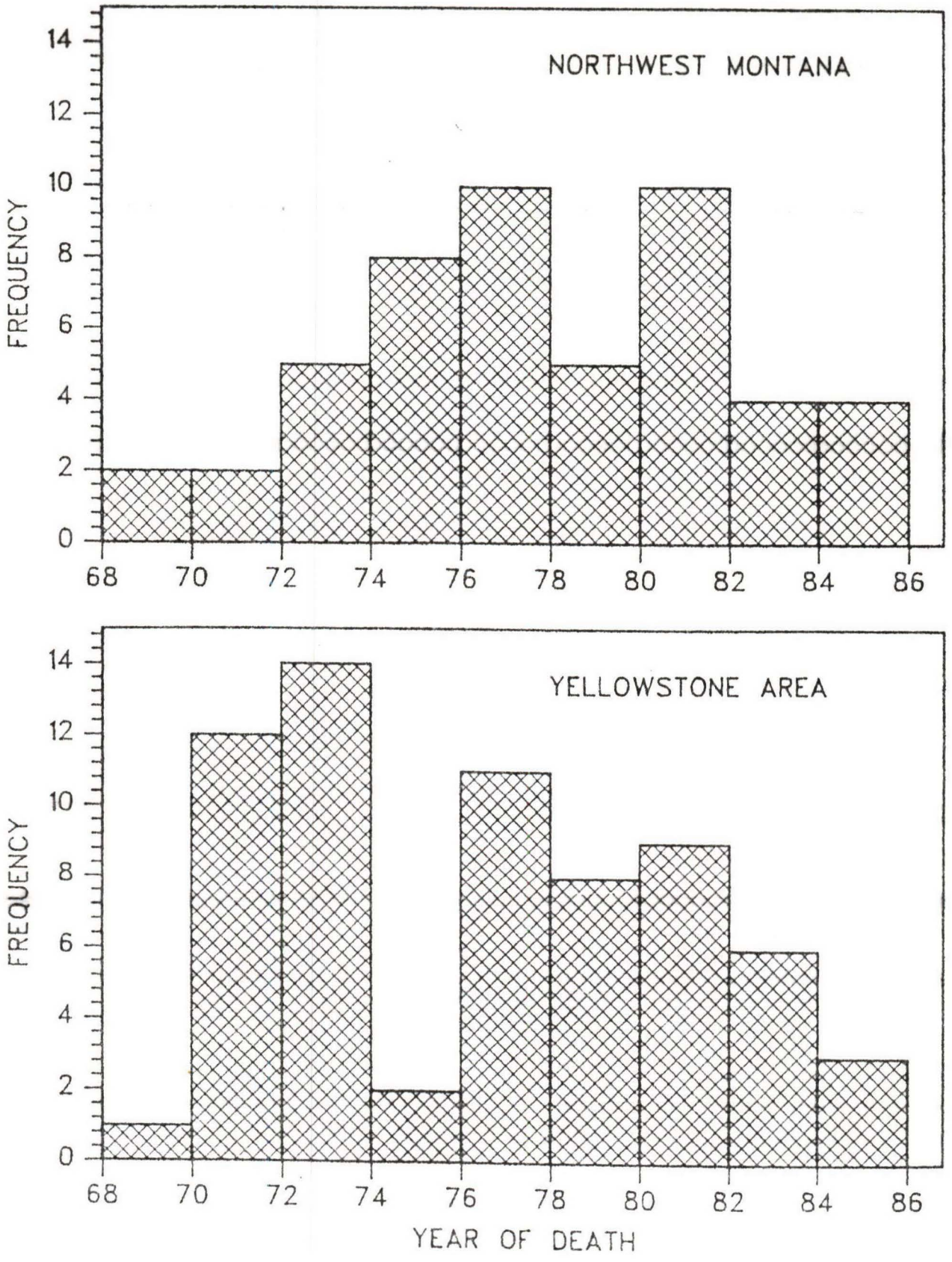

Figure 2. Frequency histograms of year of death for the two grizzly populations.

Measures of size: Since bear size is the greatest source of variation in the data, the relationships between the available morphometric measures should be carefully explored. Skull measurements are the most frequently made measurement in the MSFWP records. Table 4 indicates surprising low correlations between some of these variables, though most are significant. Skull length, skull width and femur length are essentially equivalent. Figure 3 suggests a tendency for the northern bears to have shorter skulls relative to femur length than do the Yellowstone bears, but this is not statistically significant. Skull length is not very well correlated with molar size or with tooth row lengths. For these, there is good correlation between right and left, but much weaker correlation between upper and lower or length and width. At least some of this is due to insufficient measurement precision. Some of these measures are subject to analysis for asymmetry, but this has not been examined.

Table 4. Pair-wise correlations among eleven skeletal measurements on the complete data set. Sample size varies, significance is indicated in the upper half of the matrix by NS for P > 0.05, * for P < 0.01.

	1	2	3	4	5	6	7	8	9	10	11
1. Femur length	--	**	**	**	**	**	**	*	*	NS	NS
2. Skull length	.96	--	**	**	**	**	**	*	*	NS	NS
3. Skull width	.92	.96	--	**	**	**	**	NS	*	NS	NS
4. Left molar length	.36	.47	.37	--	**	**	**	**	**	**	**
5. Right molar length	.37	.49	.38	.99	--	**	**	**	**	**	**
6. Left molar width	.30	.42	.33	.63	.63	--	**	**	**	*	**
7. Right molar width	.31	.41	.31	.60	.61	.97	--	**	**	*	*
8. Left upper teeth	.39	.45	.38	.94	.94	.68	.67	--	**	**	**
9. Right upper teeth	.37	.45	.39	.89	.89	.63	.62	.95	--	**	**
10. Left lower teeth	.14	.18	.10	.65	.65	.51	.49	.77	.70	--	**
11. Right lower teeth	.15	.17	.13	.66	.65	.55	.51	.76	.72	.99	--

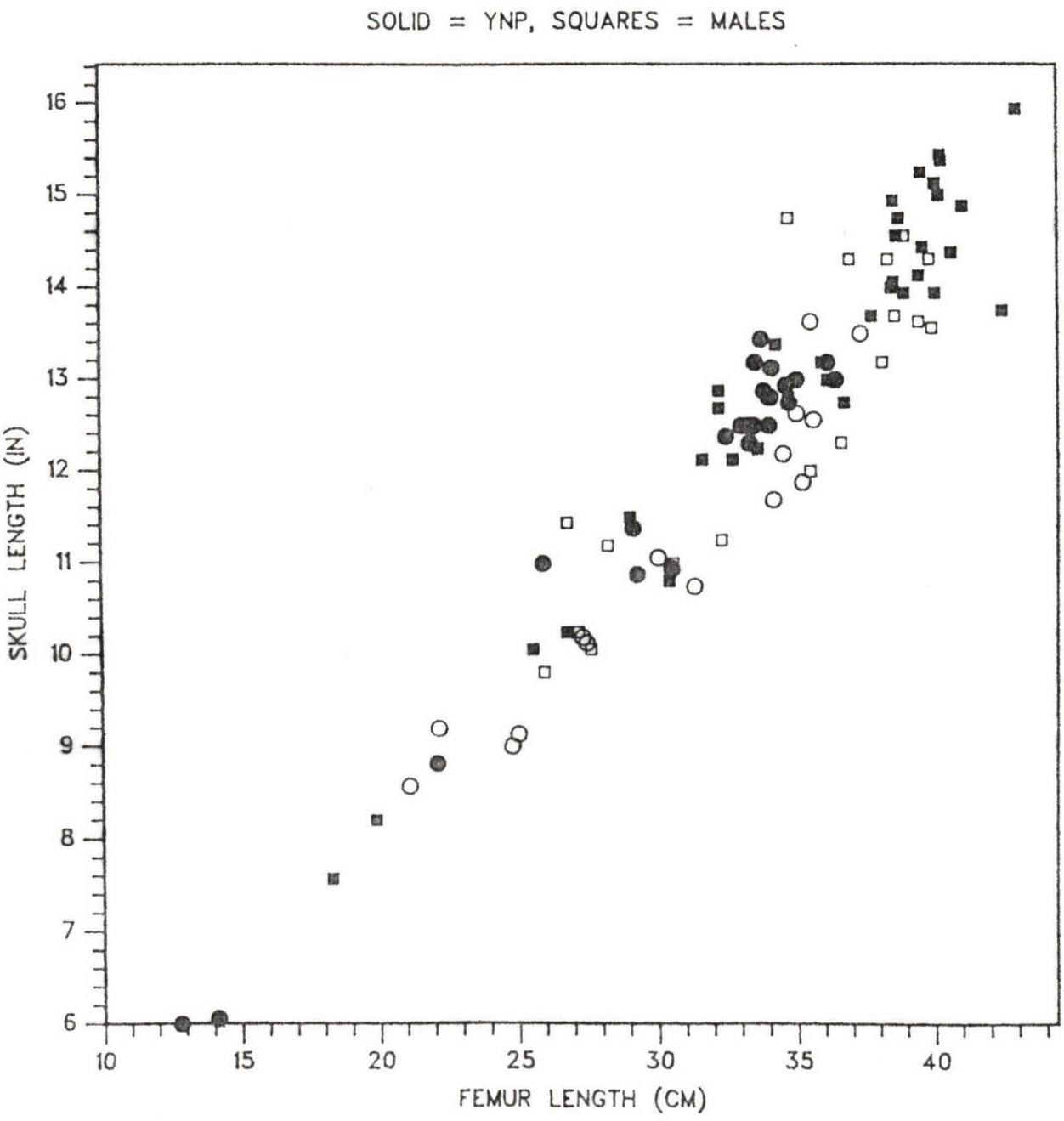

Figure 3. Linear relationship between femur length and skull length.

The correlations among the remaining measures of body size are given in Table 5. Body length is closely and linearly related to femur length (Figure 4). Chest girth is likewise linearly related to both body length and femur length, with the exception of two small-chested outliers from the Yellowstone area (Figure 4). Whole body weight increases faster than linearly with femur length (Figure 6).

Table 5. Pair-wise correlations among femur length, the three measures of body weight or size for the combined data set. Sample sizes vary, significance is indicated in the upper positions of the matrix by NS for $P > 0.05$, * for $P < 0.05$ and ** for $P < 0.01$.

	1	2	3	4
1. Femur length (cm)	--	**	**	**
2. Body length (in)	.95	--	**	**
3. Chest girth (in)	.84	.83	--	**
4. Whole weight (lb)	.82	.85	.86	--

The last eleven variables listed in Table 1 were measured specifically for this study. Femur cross-sectional area and circumference are almost totally redundant for both the outer measurement (Figure 11) and the inner measurement. This indicates little variance in the shape of the cross section so circumferences were not considered further. The correlations among the remaining variables are given in Table 6.

All variables except bone calcium and phosphorous levels are significantly correlated with femur length and therefore with overall size. Two of these, the percentage of the femur occupied

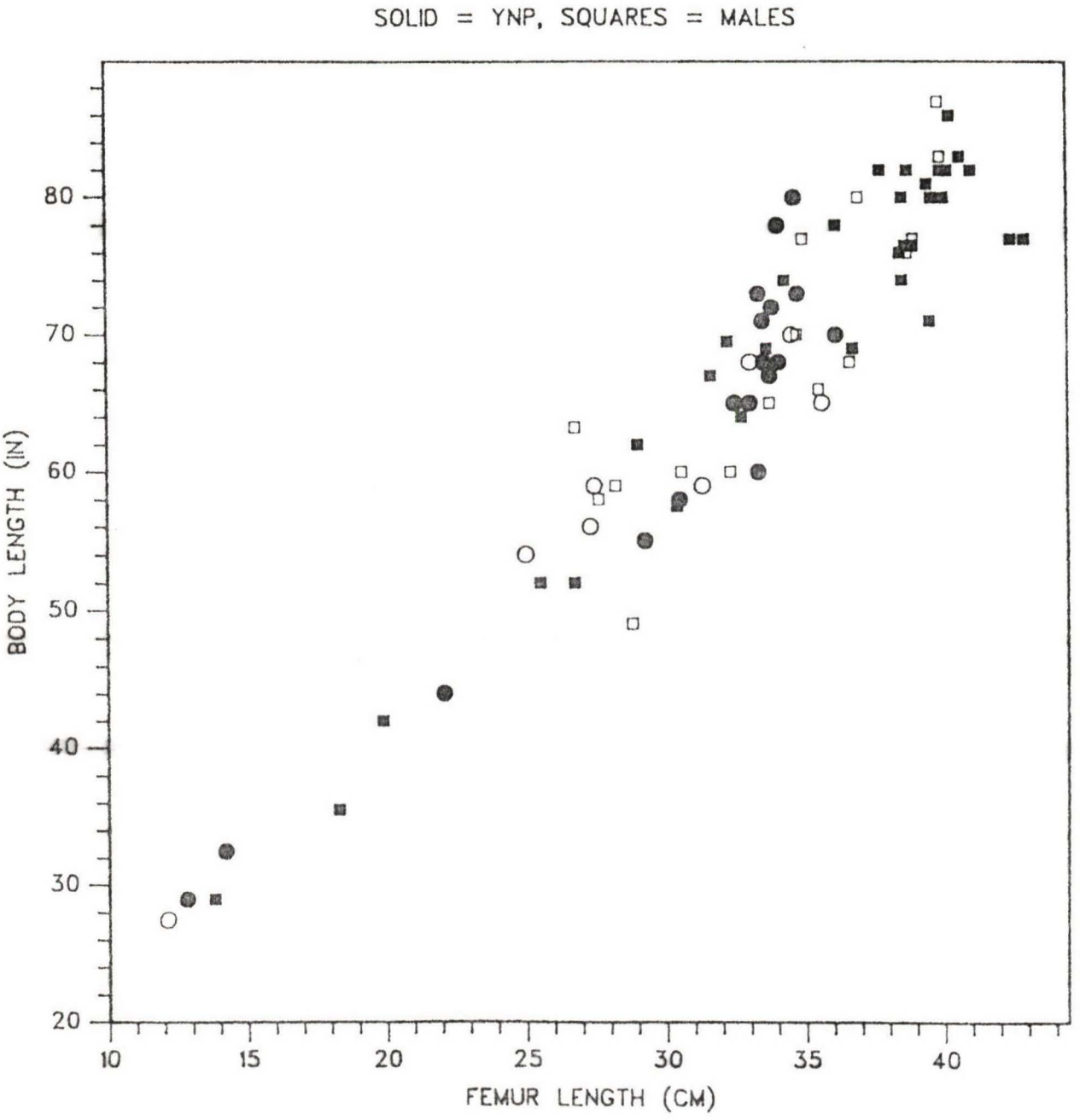

Figure 4. Linear relationship between femur length and total body length of the bears.

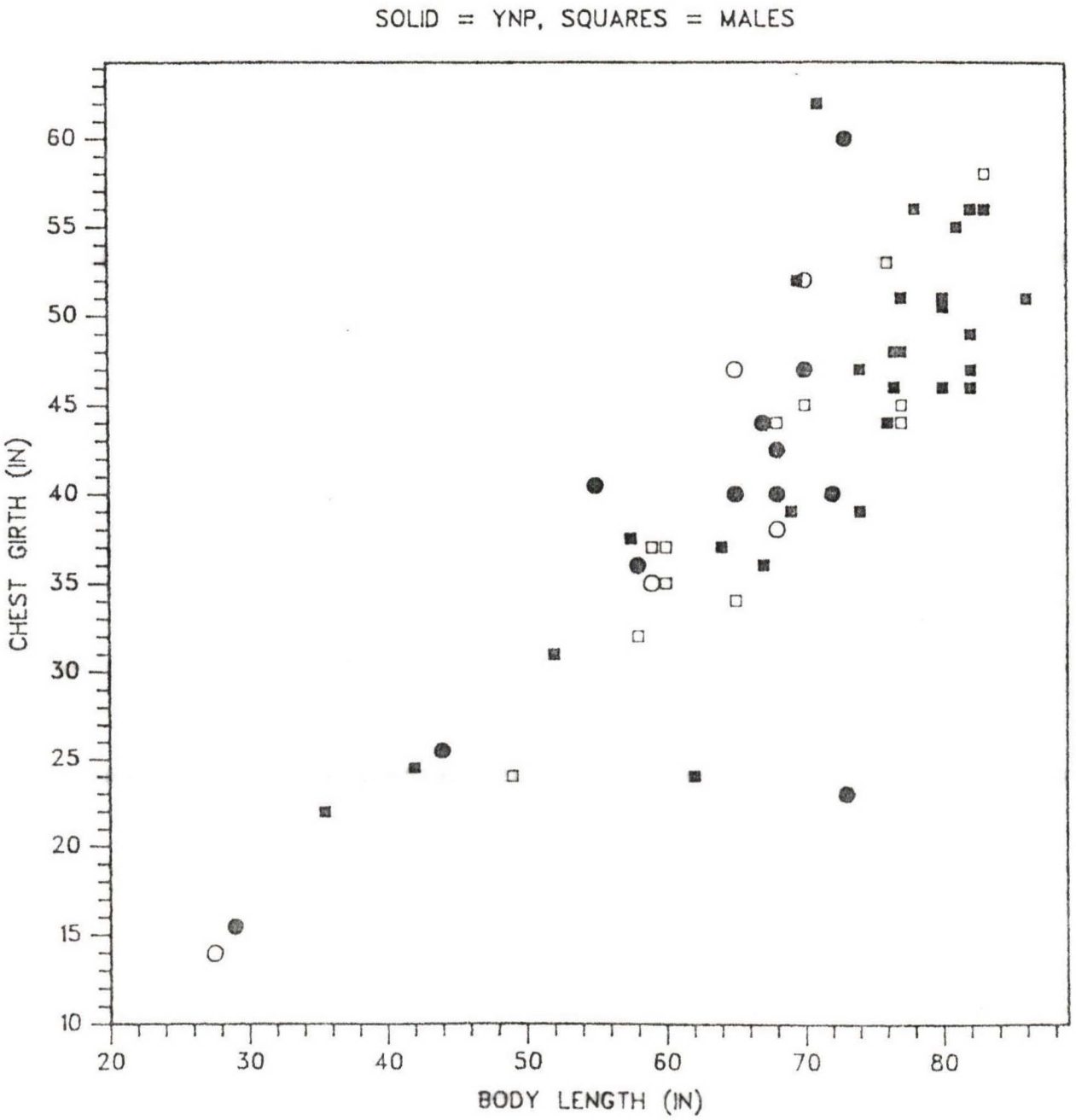

Figure 5. Linear relationship between femur length and chest girth of the bears.

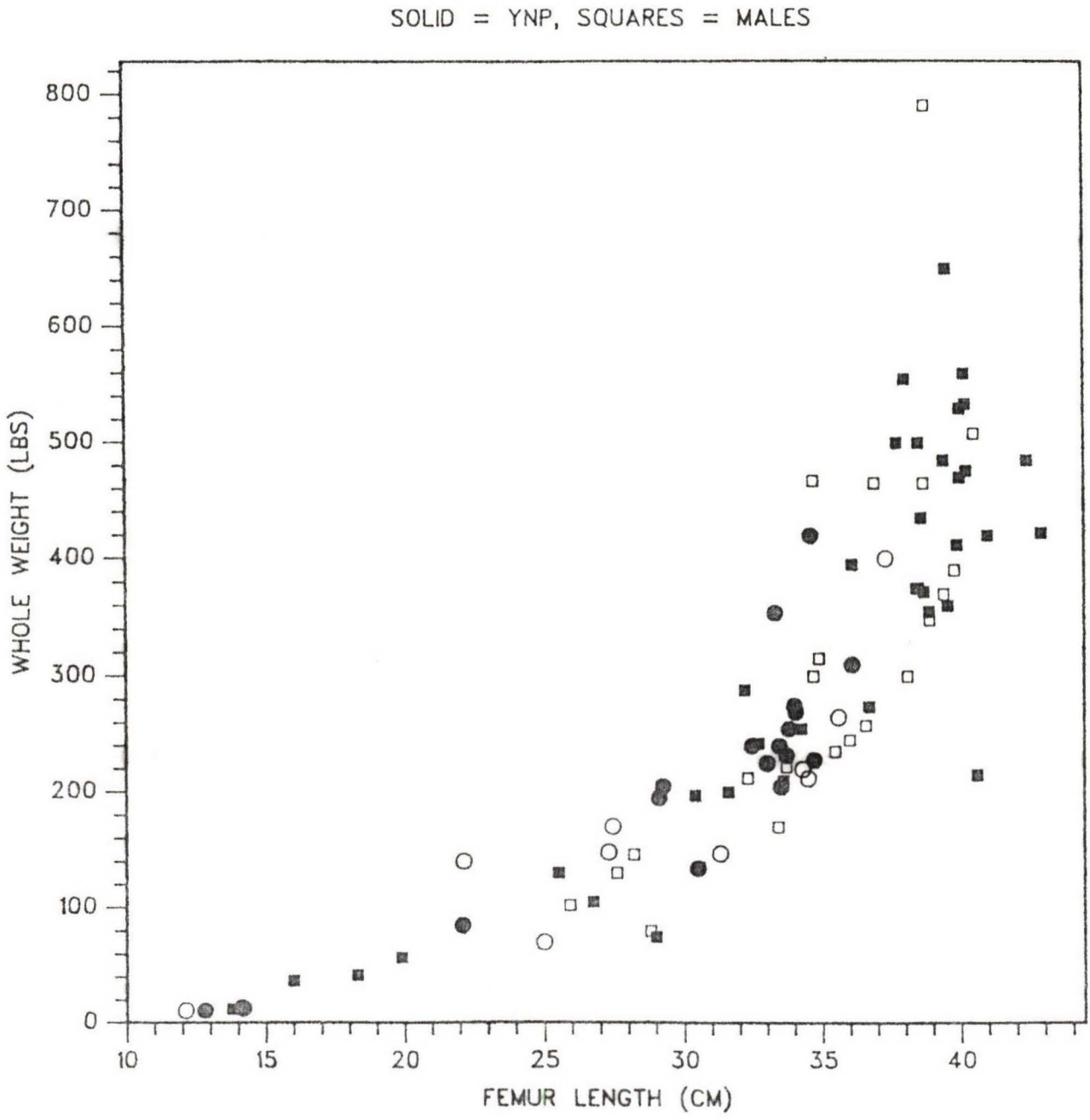

Figure 6. Power function relationship between femur length and whole body weight of the bears.

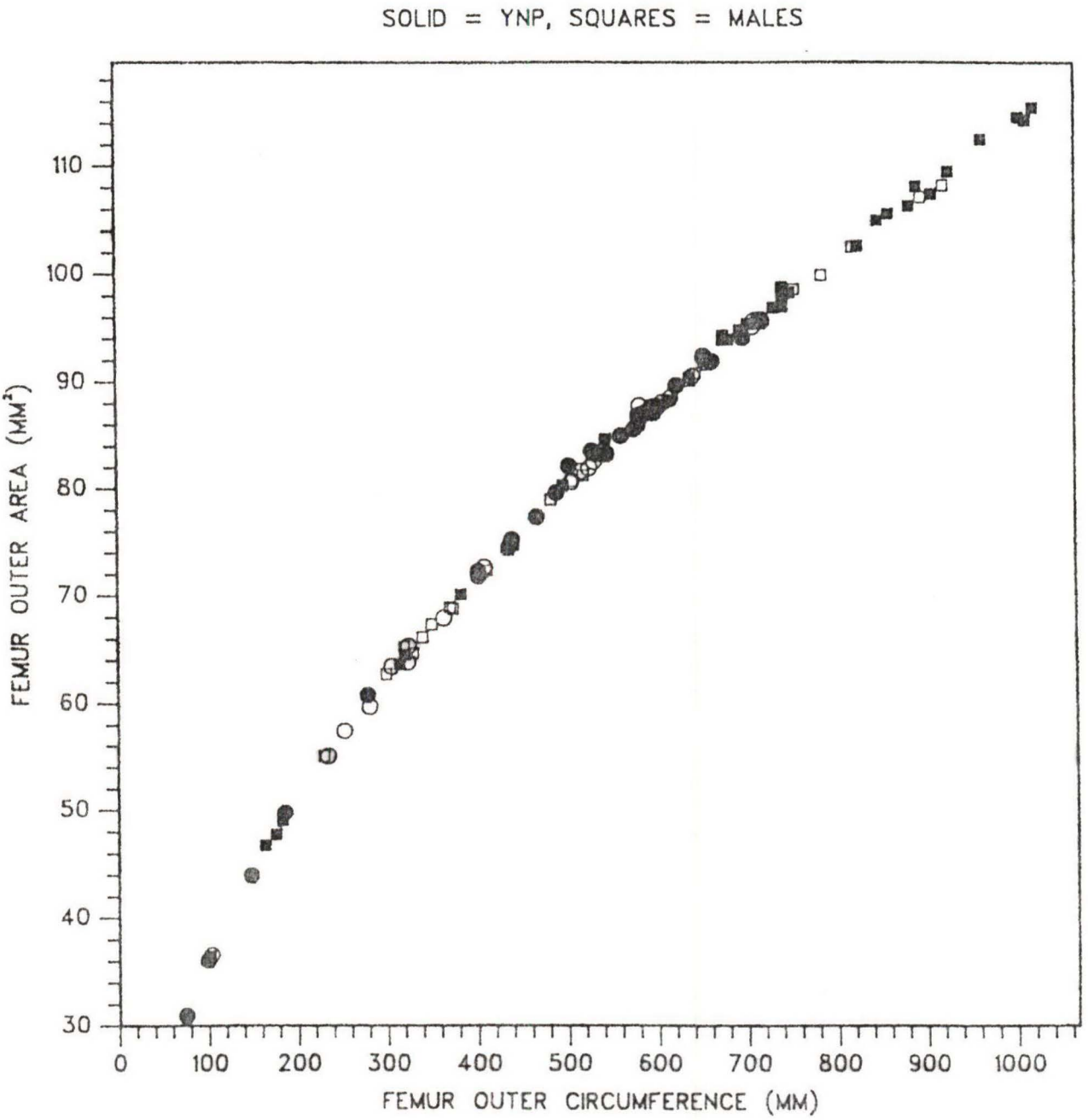

Figure 7. Simple relationship between femur cross section area and circumference showing the lack of variation in shape

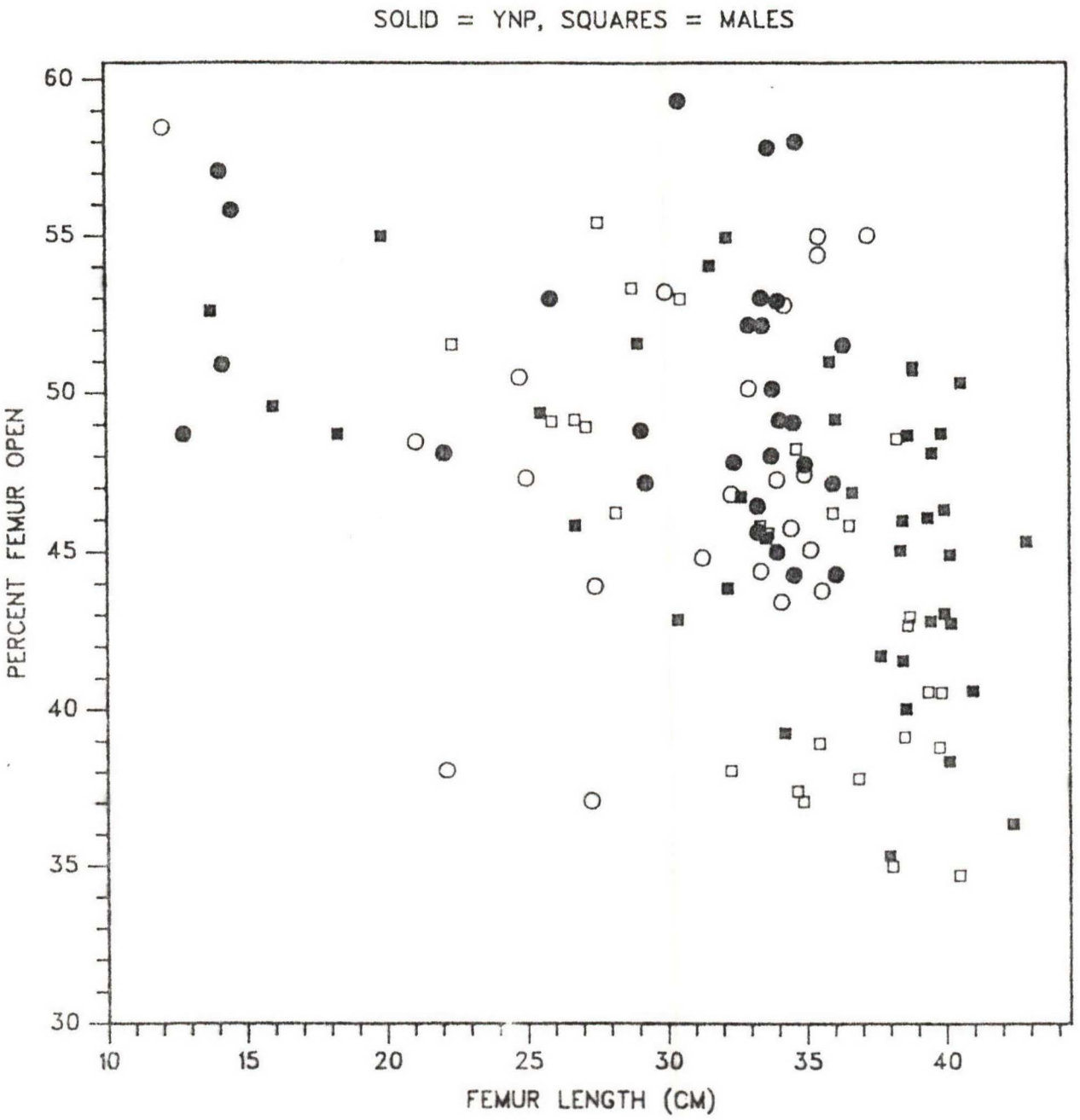

Figure 8. Femur length and percent of the femur occupied by the medullar cavity (open).

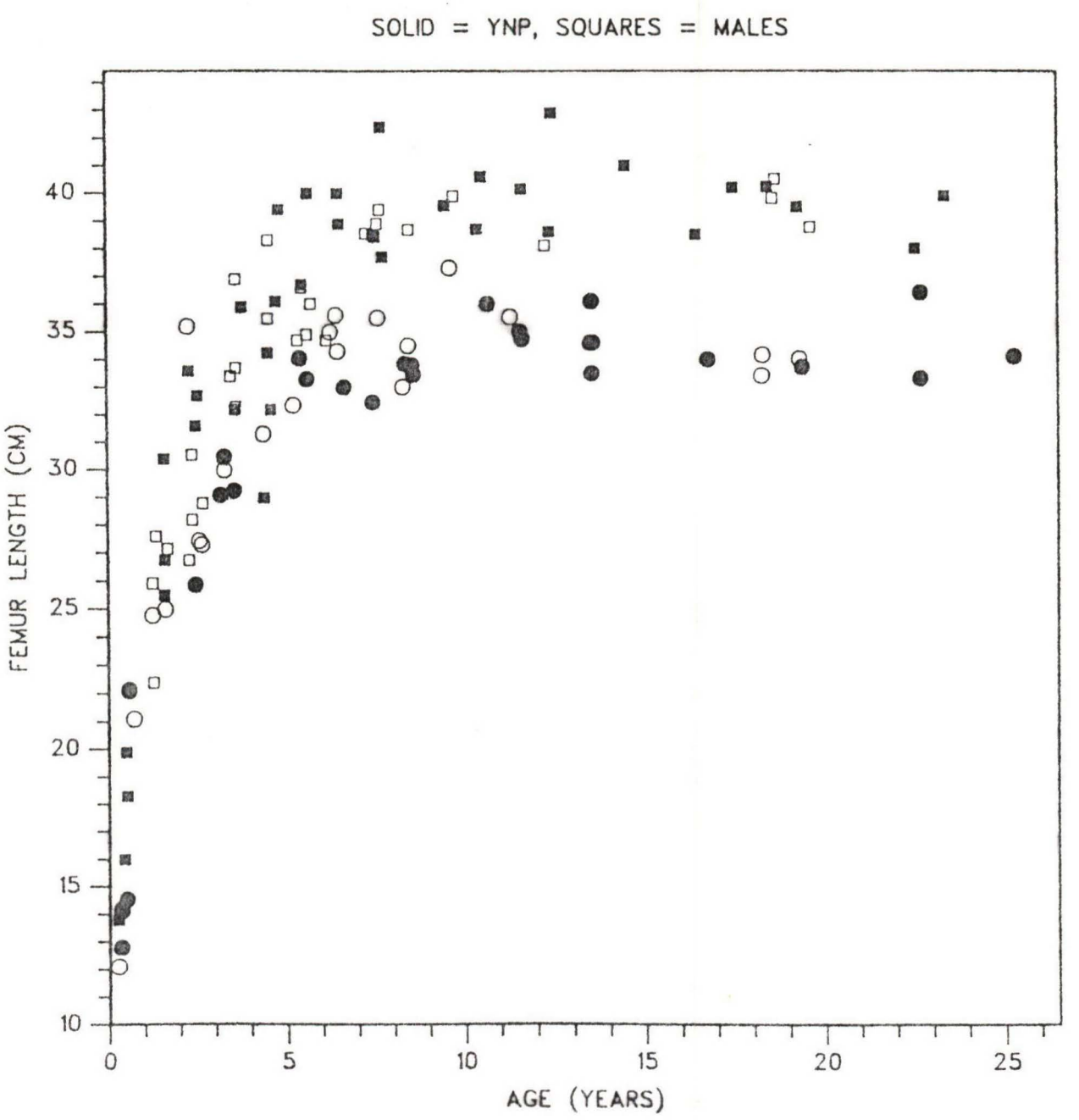

Figure 9. Growth in the femur as indicated from length at age of death.

Table 6. Pair-wise correlations among the variables measured in this study on the complete data set. Sample sizes vary, significance is indicated in the upper half of the matrix by NS for P > 0.05, * for P < 0.05 and ** for P < 0.01.

1. Femur length	--	**	**	**	**	**	NS	**	NS
2. Femur outer area	.94	--	**	**	**	**	*	NS	*
3. Femur inner area	.75	.85	--	**	**	NS	**	NS	**
4. Femur slice wt.	.89	.96	.73	--	**	**	*	NS	*
5. Femur density	.90	.96	.89	.93	--	*	*	*	*
6. Percent femur open	-.43	-.35	.18	-.47	-.22	--	NS	NS	NS
7. Percent calcium	.10	.22	.28	.20	.21	.12	--	**	**
8. Percent magnesium	-.28	-.18	-.11	-.17	-.22	.17	.67	--	**
9. Percent phosphorous	.14	.21	.25	.19	.21	.06	.88	.71	--

by the medullar cavity and the magnesium content, tend to decrease with size. This is partially due to differences between the adult males and females (Figure 8). The adult male bears are larger and also have a strong tendency to have less of the femur occupied by the medullar cavity. There is also some tendency for the adult bears from the Yellowstone area, particularly the males, to have more of the femur open than the bears from Northwest Montana. Femur density and outer cross-sectional area are nearly equivalent to femur length. The other variables are less strongly correlated and may prove valuable when examined in the context of the full structure (sex, age, year, locality and dump exposure).

Age and growth: While the measures of animal size (except the two weights) are linearly related to each other, none are linearly related to age. The skeletal measures of size appear to increase rapidly for the first two years of life, less rapidly

for the next five and to change little after that (Figures 9 and 10). By age seven, males and females generally have little or no overlap. This is more evident in femur length than in skull length. Growth in body length, bone density, and femur outer cross sectional area closely approximate growth in the skull or femur. Growth in body weight (Figure 11) and the size of the femur medullary cavity (Figure 12) are more erratic than the other variables, probably because these are more subject to change in response to short term nutritional status.

The percent of calcium in the bone increases with age, but with considerable scatter and some tendency to be less in males (Figure 13). The percent of the femur occupied by the medullar cavity decreases with age, but with greater scatter and with a marked tendency to be lower in males (Figure 14).

For the Yellowstone area, the temporal pattern, age structure and dump closures (1968-1971) result in a complex structure (Figure 15). Solid symbols in region I of the figure represent Yellowstone area bears which had access to the dumps for their entire life. The data set includes very few of these animals. The Yellowstone area bears in region II had access to the dumps for at least the first seven years of their life. These 19 bears (including region I bears over 7 years of age) are necessarily at least seven years old when collected an average 16.6 years. The only Yellowstone area bears with no access to the dumps are those in region IV. These 32 bears are necessarily young, the oldest in the sample being less than 9 and the average being 4.3 years. Because of the gross differences in ages, these

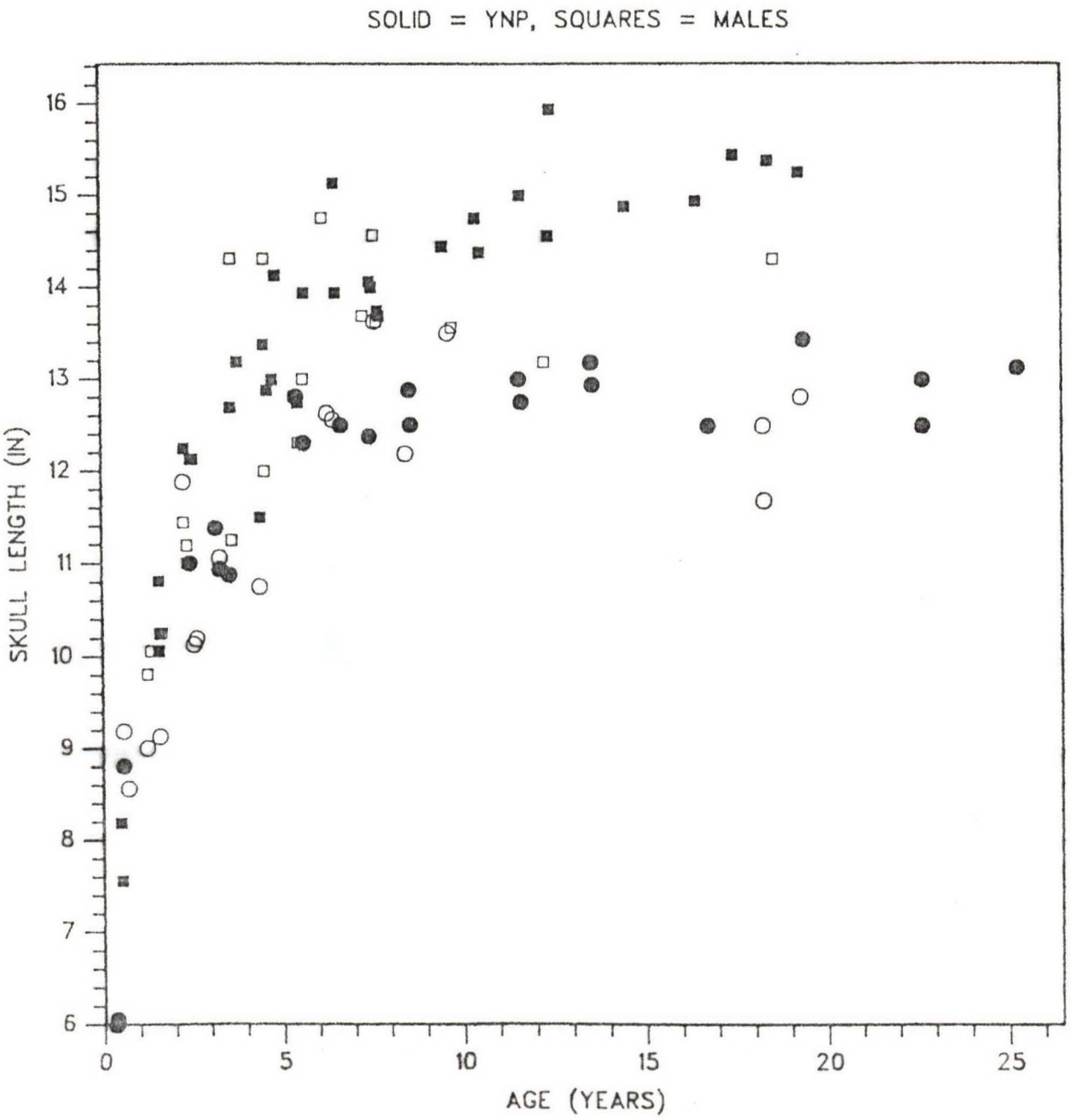

Figure 10. Growth in the skull as indicated from length at age of death.

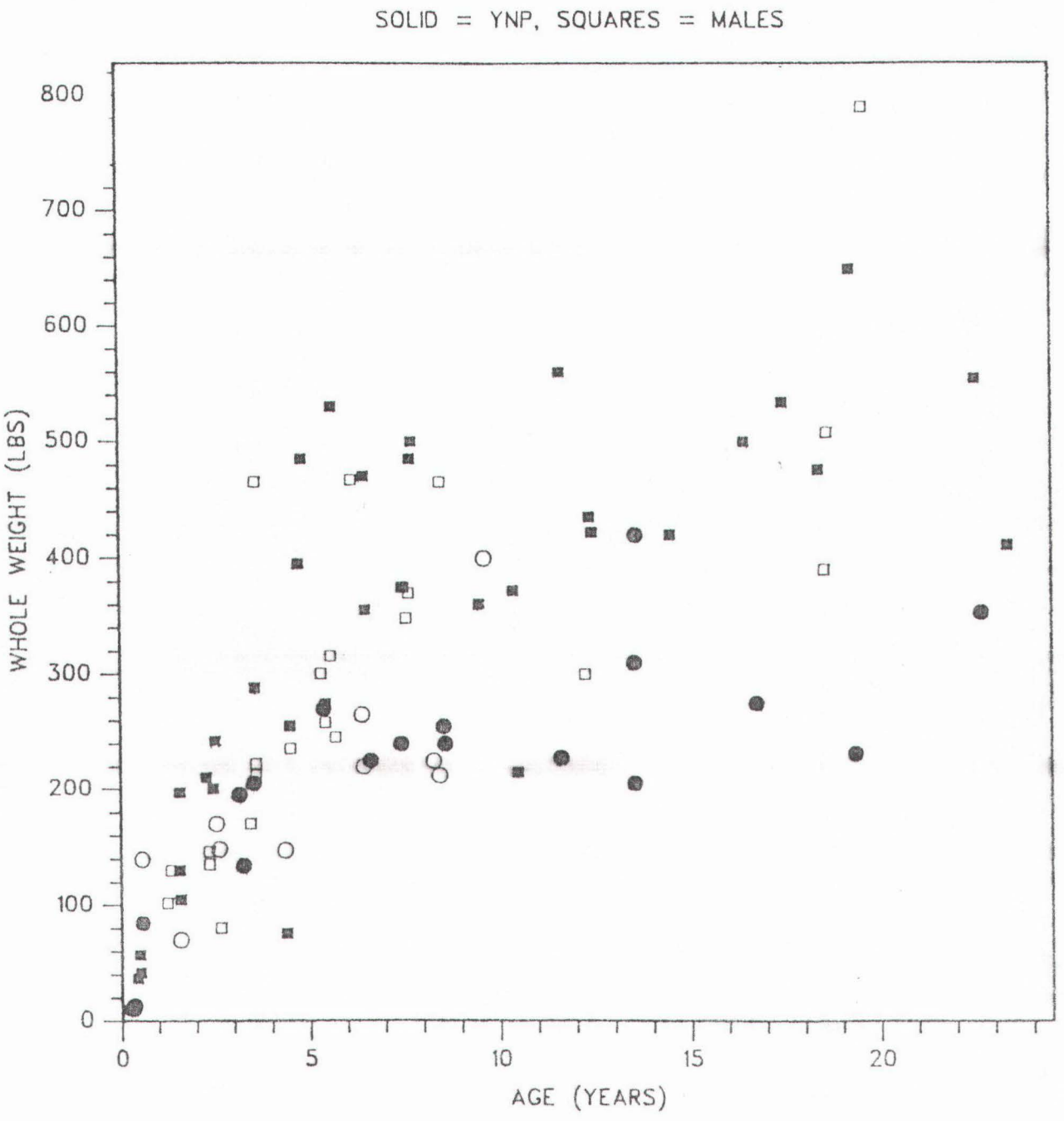

Figure 11. Growth in body weight as indicated from weight at age of death.

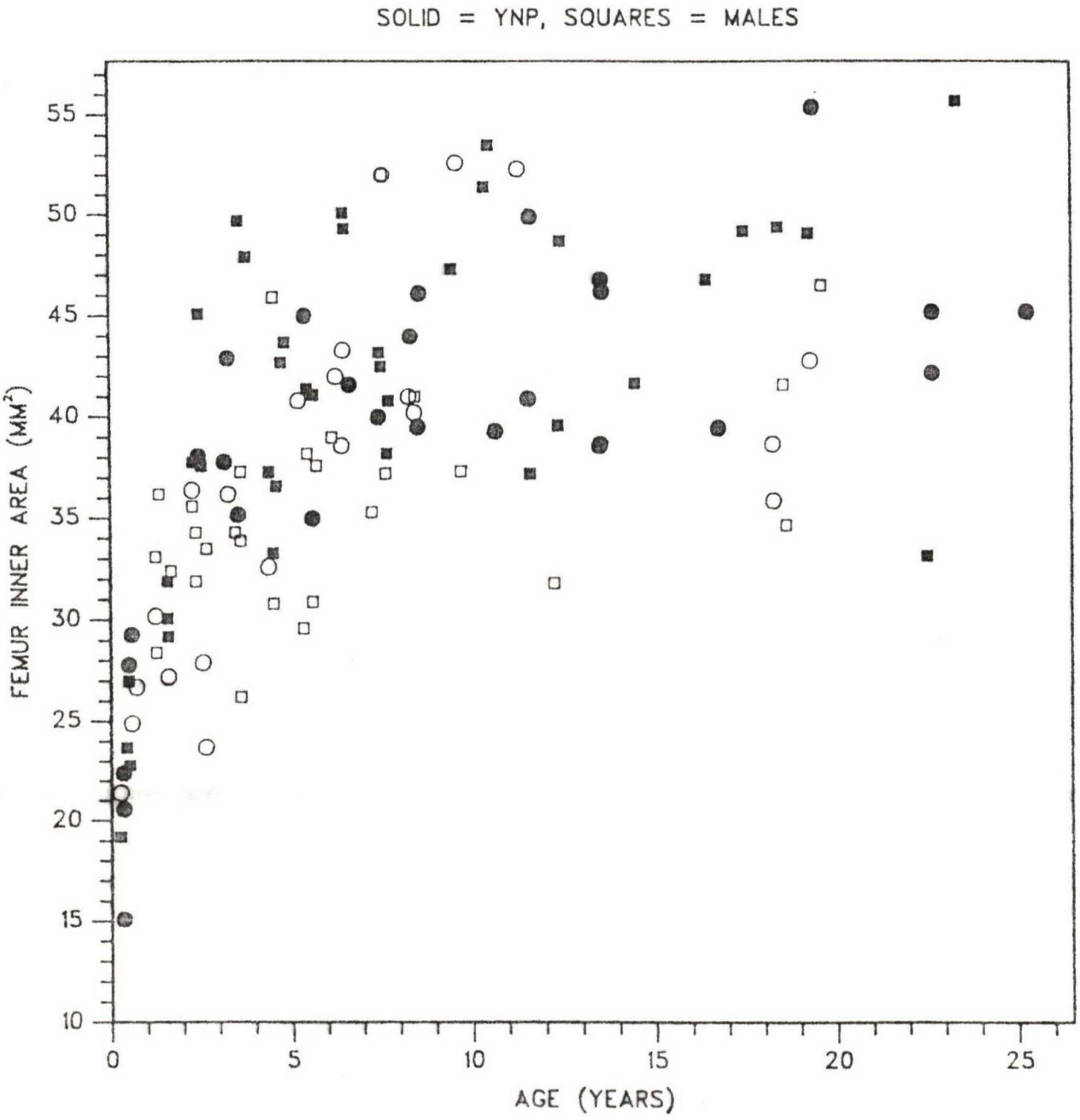

Figure 12. Growth in the femur medullar cavity as indicated from cross sectional area at the age of death.

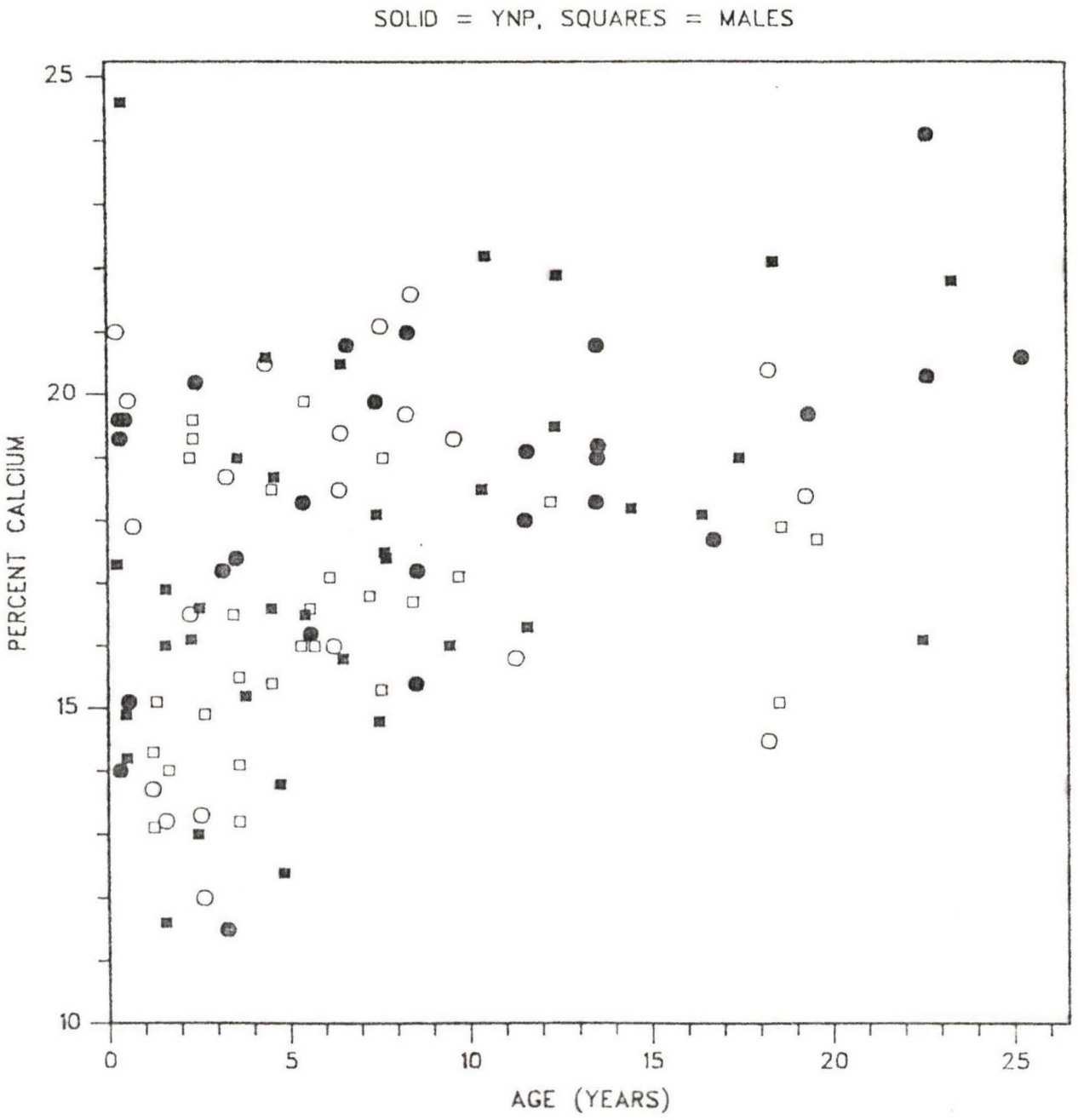

Figure 13. Change in percent calcium composition of the bone with age.

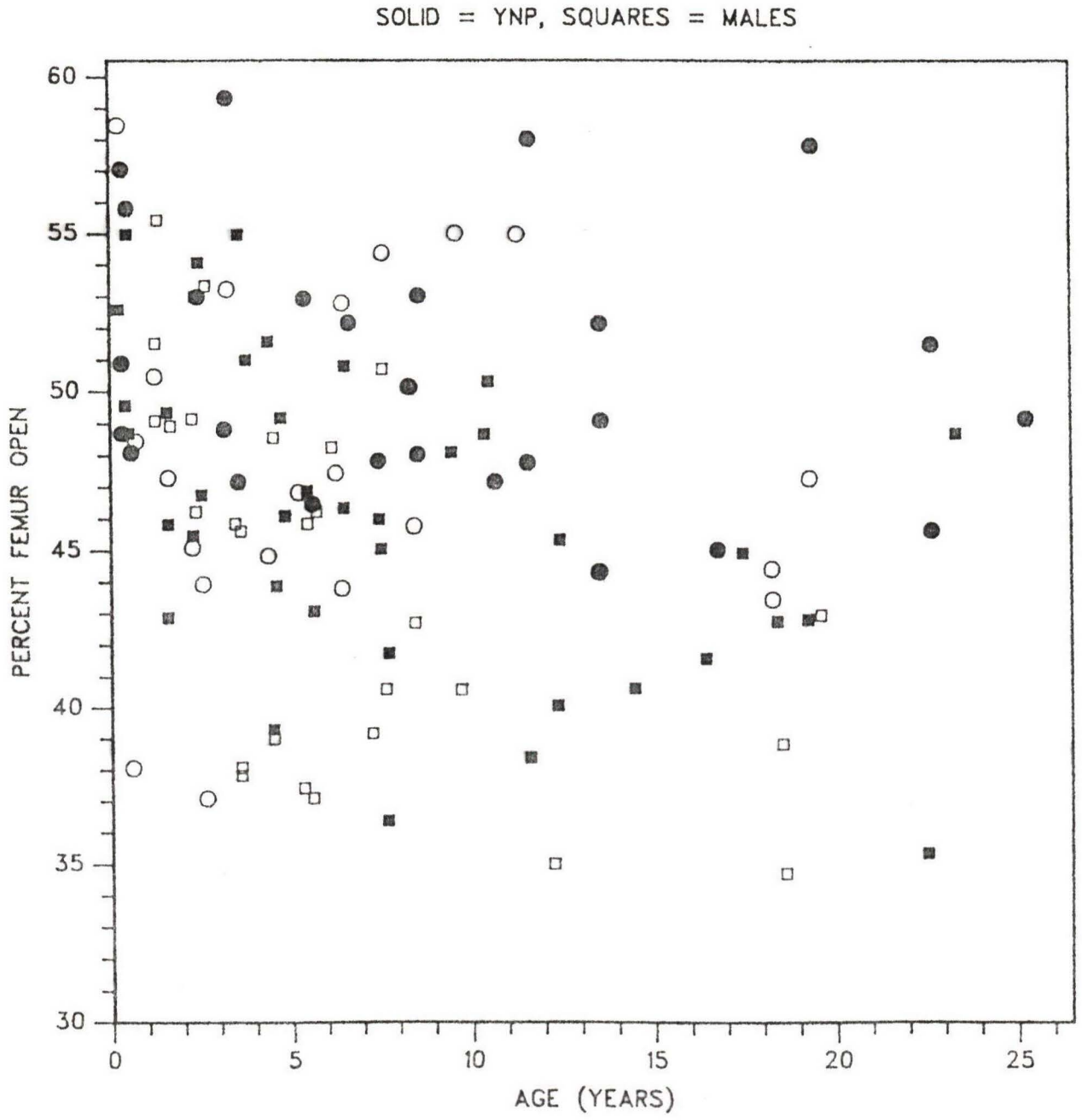

Figure 14. Percent of the femur occupied by the medullar cavity (open) and the age of bear at death.

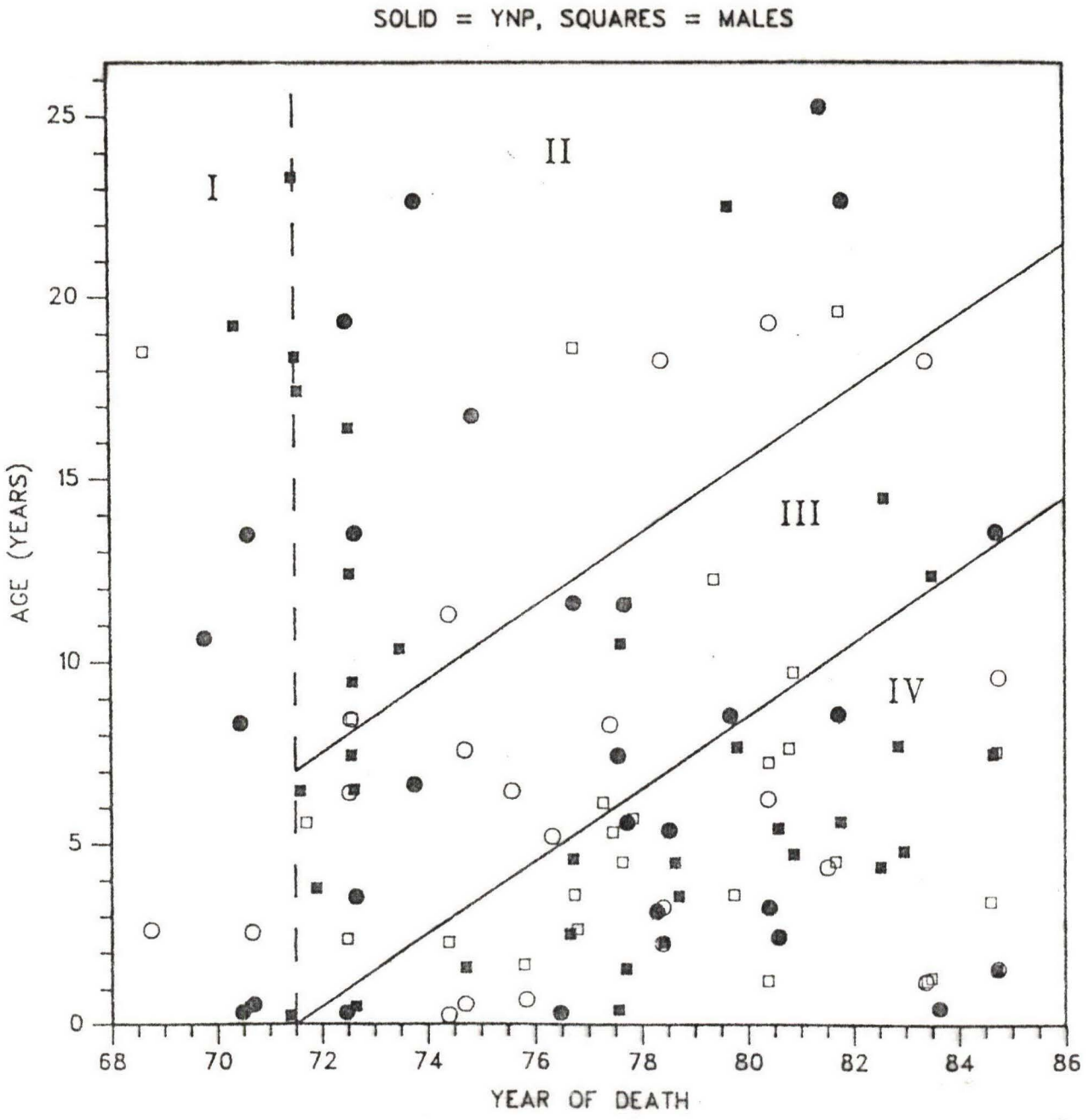

Figure 15. **The age and time dependent accessibility to the Yellowstone dumps which were closed by mid 1971** (dotted vertical line). A yellowstone area bear in region I would have had access to the dumps for its entire life, while those in region II had access for at least the first seven years of life, those in region III for the first one to six years of life and those in region I/ had no access to the park dumps.

two groups cannot be directly compared for difference in any variable which changes with age. Yellowstone area bears in region III spent the first one to six years of their lives with access to the dumps. These 15 bears were of limited use in this analysis because of the small sample size.

Once the statistical analysis of the 116 bears in the skeletal collection was completed it became obvious the sample size was not large enough to allow meaningful and statistically significant conclusions to be made about the impact of dump closures. In order to properly analyze the data set the bears had to be highly structured over time (pre and post dump closing), space (between YNP and Northern Montana population), sex and age. As a result, the small number of bears in each subsample made conclusions subject to a variety of interpretations.

Therefore, in October of 1987 we requested permission from the MDFWP to expand the data set to include data from all grizzly carcasses measured by their field investigators between 1967 and 1984. This involved some 366 additional (non-skeletal) bears collected from both YNP and the Northern Montana populations. The data was in the form of field data sheets catalogued by year at the MDFWP regional headquarters at Bozeman.

In late april 1988 permission was granted to use the additional data.

Approximately thirty bears were eliminated from the study due to factors such as missing skulls, broken skulls etc. at the time of their original collection. Therefore, 336 bears were

added to the study giving a total of 452 bears analyzed.

Bears in the original 116 sampled (skeletal collection) had been analyzed for up to 58 different factors dependent upon whether the data was taken at the time of the bears death.

For the expanded sample (non-skeletal) the data was limited to MDFWP serial #, date of collection, sex, area, age, skull length and width for most specimens and body length, chest girth and whole weight when available (Table #7).

Analysis of the data from our research done on the original 116 skeletal collection bears had shown that pair wise correlations between femur length and skull length were highly significant ($P < 0.01$ - Table 4).

This is also reflected in the linear relationship between femur length and skull length shown in Figure 3 (page 15).

As skull length measurements were available for 422 of the 452 bears it was decided that efforts to determine if growth changes had occurred due to dump closures could best be documented using this variable.

The sample populations were further refined to eliminate 14 bears where the field data forms had either missing or questionable data, mostly involving the sex of the carcass.

Therefore, a total of 408 bears were analyzed, 137 from YNP and 271 from the Northern Montana populations (NMT).

The YNP sample contained 80 males and 57 females. The NMT sample contained 148 males and 123 females.

Table 7. Summary of grizzly bear data.

	VARIABLE	N	NZERO	MEAN	STD	MIN	MAX
1	MDFWP SERIAL #	452	0			176441.000	179290.000
2	MONTH	452	0	8.635	1.906	2.000	12.000
3	DAY	452	0	17.507	8.116	1.000	31.000
4	YEAR	452	0	75.000	5.135	67.000	84.000
5	SEX (M=1,F=2)	452	0	1.442	.497	1.000	2.000
6	AREA (1=NMT,2=YNP)	452	0	1.338	.473	1.000	2.000
7	SKULL LENGTH (IN)	422	0	12.470	1.610	6.000	16.125
8	SKULL WIDTH (IN)	428	0	6.920	1.125	3.440	9.875
9	LEFT MOLAR LENGTH (M	95	0	36.284	2.457	30.000	41.000
10	RIGHT MOLAR LENGTH (	93	0	36.366	2.466	30.000	41.000
11	LEFT MOLAR WIDTH (MM	95	0	18.947	1.060	17.000	21.000
12	RIGHT MOLAR WIDTH (M	93	0	18.946	1.071	17.000	21.000
13	TOOTH AGE (YEARS)	452	20	7.334	5.989	.000	30.000
14	UPPER SKULL WT. (G)	11	0	988.091	592.363	84.000	1776.000
15	LOWER SKULL WT. (G)	11	0	405.727	254.082	32.000	771.000
16	TOTAL SKULL WT. (G)	11	0	1393.364	818.696	116.000	2457.000
17	LEFT UPPER TEETH (MM	29	0	74.703	4.234	66.400	82.600
18	RIGHT UPPER TEETH (M	30	0	74.183	4.246	64.600	81.800
19	LEFT LOWER TEETH (MM	24	0	80.983	5.002	73.200	88.600
20	RIGHT LOWER TEETH (M	25	0	81.408	4.626	73.200	89.000
21	CONDITION CODE (1=BE	56	0	2.161	.819	1.000	4.000
22	CAUSE OF DEATH	103	0	2.359	.666	1.000	5.000
23	ZYGOMATIC WIDTH (IN)	35	0	7.293	1.755	3.630	10.380
24	BODY LENGTH (IN)	119	0	68.229	13.124	27.500	90.500
25	CHEST GIRTH (IN)	90	0	43.595	11.780	14.000	102.360
26	WHOLE WEIGHT (LB.)	136	0	282.643	155.852	11.000	790.000
27	EVISC WT. (LB.)	12	0	222.250	125.188	29.000	442.000
28	HIDE WT. (LB.)	24	0	32.500	19.218	4.000	80.000
29	KIDNEY WT. (G)	74	0	247.081	124.922	20.000	603.000
30	KIDNEY FAT WT. (G)	74	2	135.426	116.734	.000	506.000
31	LEFT FRONT CLAW (IN)	90	0	2.903	.762	1.130	4.500
32	RIGHT FRONT CLAW (IN	102	0	2.989	.808	1.130	5.000
33	FRONT PAD WIDTH (IN)	117	0	5.149	1.007	2.250	7.250
34	FRONT PAD LENGTH (IN	116	0	2.609	.639	.880	5.240
35	FRONT FOOT TO CLAWS	104	0	4.493	.997	1.750	9.500
36	FRONT FOOT WITH CLAW	102	0	6.265	1.159	2.500	8.500
37	REAR PAD WIDTH (IN)	107	0	4.709	.913	2.000	7.000
38	REAR PAD LENGTH (IN)	107	0	6.515	1.340	2.250	10.250
39	REAR FOOT TO CLAWS(I	104	0	8.242	1.534	3.000	11.250
40	REAR FOOT WITH CLAWS	104	0	9.151	1.636	3.500	12.500
41	FEMUR OUTER AREA (MM	116	0	82.229	17.971	31.000	115.500
42	FEMUR OUTER CIRCUMFE	116	0	548.216	215.230	74.400	1019.700
43	FEMUR INNER AREA (MM	116	0	38.338	8.401	15.100	55.700
44	FEMUR INNER CIRCUMFE	116	0	116.798	48.127	17.000	241.500
45	FEMUR LENGTH (CM)	116	0	32.659	6.928	12.100	42.900
46	FEMUR SLICE WT. (G)	116	0	4.052	1.796	.343	8.633
47	PERCENT CALCIUM	112	0	17.506	2.681	11.500	24.600
48	PERCENT MAGNESIUM	112	0	.280	.053	.170	.450
49	PERCENT PHOSPHOROUS	112	0	7.749	1.164	4.600	10.100
50	AGE (YEARS)	452	1	7.878	5.983	.000	30.496

Table 7. (cont.)

51 FEMUR DENSITY (G/CM^	116	0	17.456	4.487	4.314	26.360
52 PERCENT FEMUR OPEN	116	0	47.051	5.520	34.735	59.336
53 YEAR OF DEATH	452	0	75.680	5.147	67.351	84.814
54 DUMP ACCESS (YEARS)	452	156	4.860	6.090	.000	30.496
55 SKULL RESID YNP (CM)	422	0	-1.519	1.847	-7.046	4.404
56 SKULL RESID GNP (CM)	422	0	.472	1.848	-5.247	5.830
57 EXPOSURE (4=NONE)	452	0	2.507	1.303	1.000	4.000
58 SKULL LENGTH/WIDTH	418	0	1.813	.105	1.535	2.195

Table 8. Skull length/width comparisons by sex and area.

Factor = SEX (M=1,F=2)
Variable = SKULL LENGTH/WIDTH

Levels:	total	1	2
N:	418	234	184
Means:	1.813	1.820	1.805
std:	.105	.111	.097
effects:		.007	-.009

Source	SS	df	MS	F	P
Treatments:	.024	1	.024	2.192	.279
Error:	4.575	416	.011		
Total:	4.599	417			

Factor = AREA (1=NMT,2=YNP)
Variable = SKULL LENGTH/WIDTH

Levels:	total	1	2
N:	418	273	145
Means:	1.813	1.817	1.805
std:	.105	.102	.110
effects:		.004	-.008

Source	SS	df	MS	F	P
Treatments:	.014	1	.014	1.248	.529
Error:	4.585	416	.011		
Total:	4.599	417			

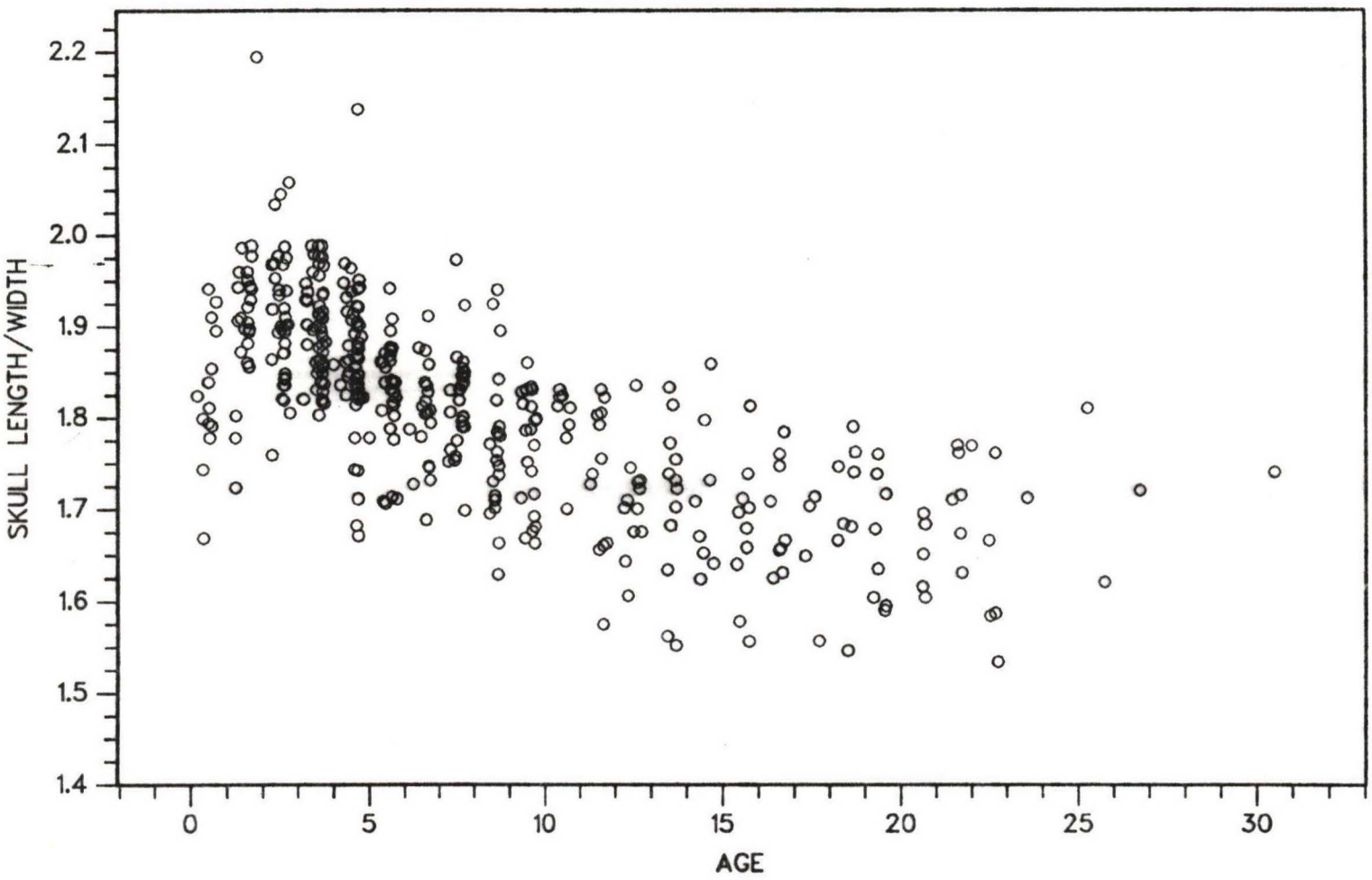

Figure 16. Skull length/width by age for 418 bears in both YNP and NMT populations.

Results

Skull measurements showed a considerable difference both within populations (by sex for both YNP and NMT), within the YNP population by year (both sexes) and between the 2 populations.

Skull length/width declined with age for all bears (Figure 16) and ranged from 1.54 to 2.20 with an overall mean of 1.81 (Table 7). Means were higher for males (1.82 to 1.80 for females) and slightly higher for all bears from the NMT sample than for the YNP sample (1.817 vs. 1.805, Table 8).

Mean skull length was greater for Yellowstone males (13.55 inches) than for Yellowstone females (12.63 inches). A similar sexual difference was found in the Northern Montana population with males having a mean skull length of 12.68 inches to 11.96 inches for females (Table 9).

Differences between sexes become even more pronounced when mean averages for sexes are considered. Females were almost 2 1/2 years older than males in each of the populations (Table 9). Growth curves for both populations show skull length increasing until approximately the age of 7 for females and 11 for males (Figures 17 and 18). Therefore, mean ages for females in both populations were past the age where maximum skull length is achieved (9.19 for NMT, 12.63 for YNP, Table 9). However, mean ages for males in both populations were considerably under the age where maximum skull length is achieved (11) for males, being 6.78 years for the NMT populations and 7.81 for the YNP population (Table 9).

Table 9. Comparisons of skull length and age by sex for NMT group and YNP group.

No. Montana Group

Factor = SEX (M=1,F=2)
Variable = SKULL LENGTH (IN)

Levels:	total	1	2
N:	271	148	123
Means:	12.356	12.682	11.963
std:	1.231	1.393	.853
effects:		.326	-.393

Source	SS	df	MS	F	P
Treatments:	34.761	1	34.761	24.989	.000
Error:	374.190	269	1.391		
Total:	408.951	270			

Factor = SEX (M=1,F=2)
Variable = AGE (YEARS)

Levels:	total	1	2
N:	271	148	123
Means:	7.873	6.779	9.191
std:	5.887	5.270	6.326
effects:		-1.095	1.317

Source	SS	df	MS	F	P
Treatments:	390.814	1	390.814	11.726	.001
Error:	8965.095	269	33.327		
Total:	9355.909	270			

YNP Group

Factor = SEX (M=1,F=2)
Variable = SKULL LENGTH (IN)

Levels:	total	1	2
N:	137	80	57
Means:	13.170	13.554	12.631
std:	1.484	1.739	.761
effects:		.384	-.539

Source	SS	df	MS	F	P
Treatments:	28.348	1	28.348	14.106	.001
Error:	271.299	135	2.010		
Total:	299.646	136			

Factor = SEX (M=1,F=2)
Variable = AGE (YEARS)

Levels:	total	1	2
N:	137	80	57
Means:	8.866	7.813	10.344
std:	5.832	5.150	6.433
effects:		-1.053	1.478

Source	SS	df	MS	F	P
Treatments:	213.353	1	213.353	6.527	.023
Error:	4413.033	135	32.689		
Total:	4626.386	136			

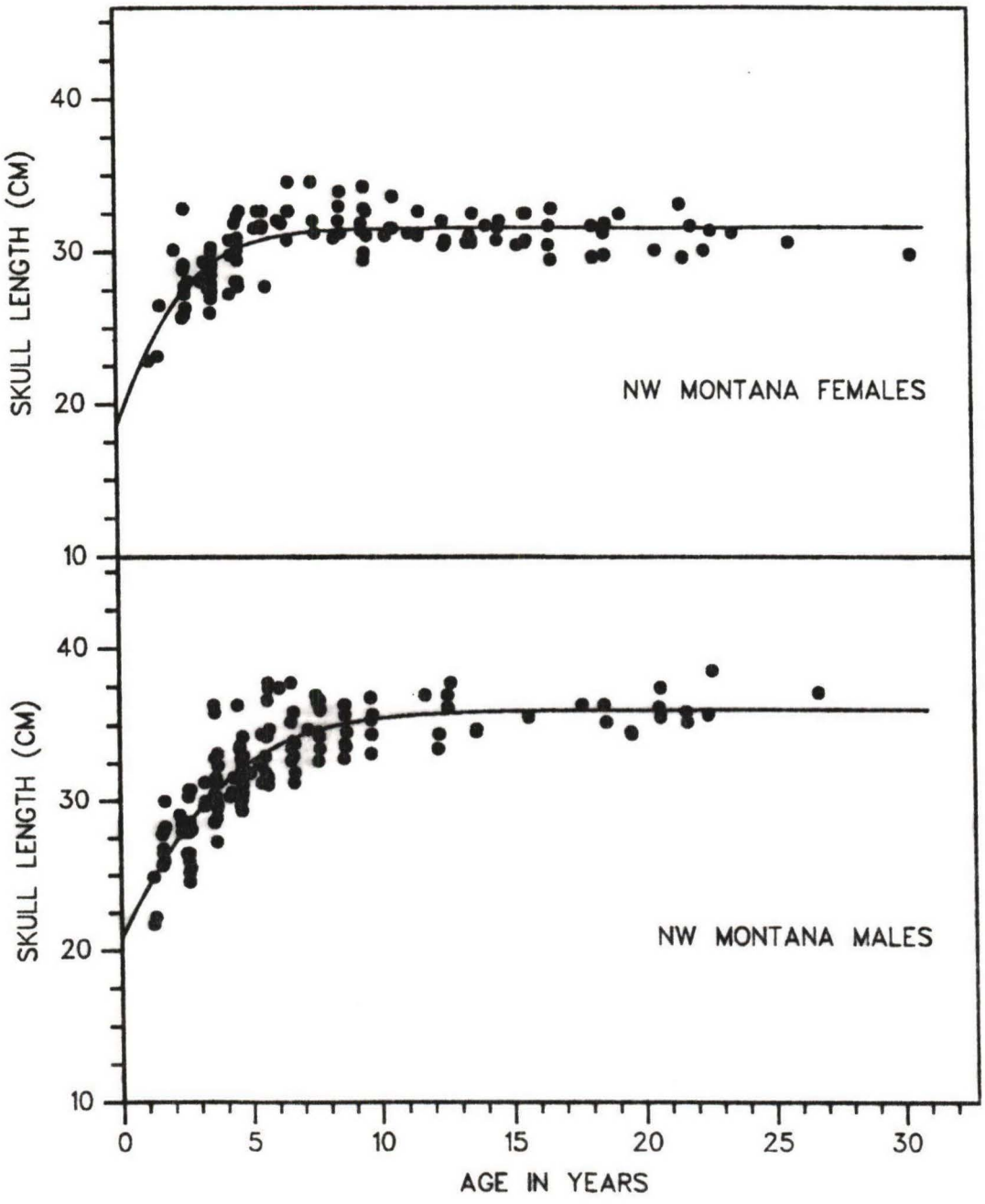

Figure 17. Growth in skull length by age for 123 NMT female grizzlies (top graph) and 148 males (lower graph).

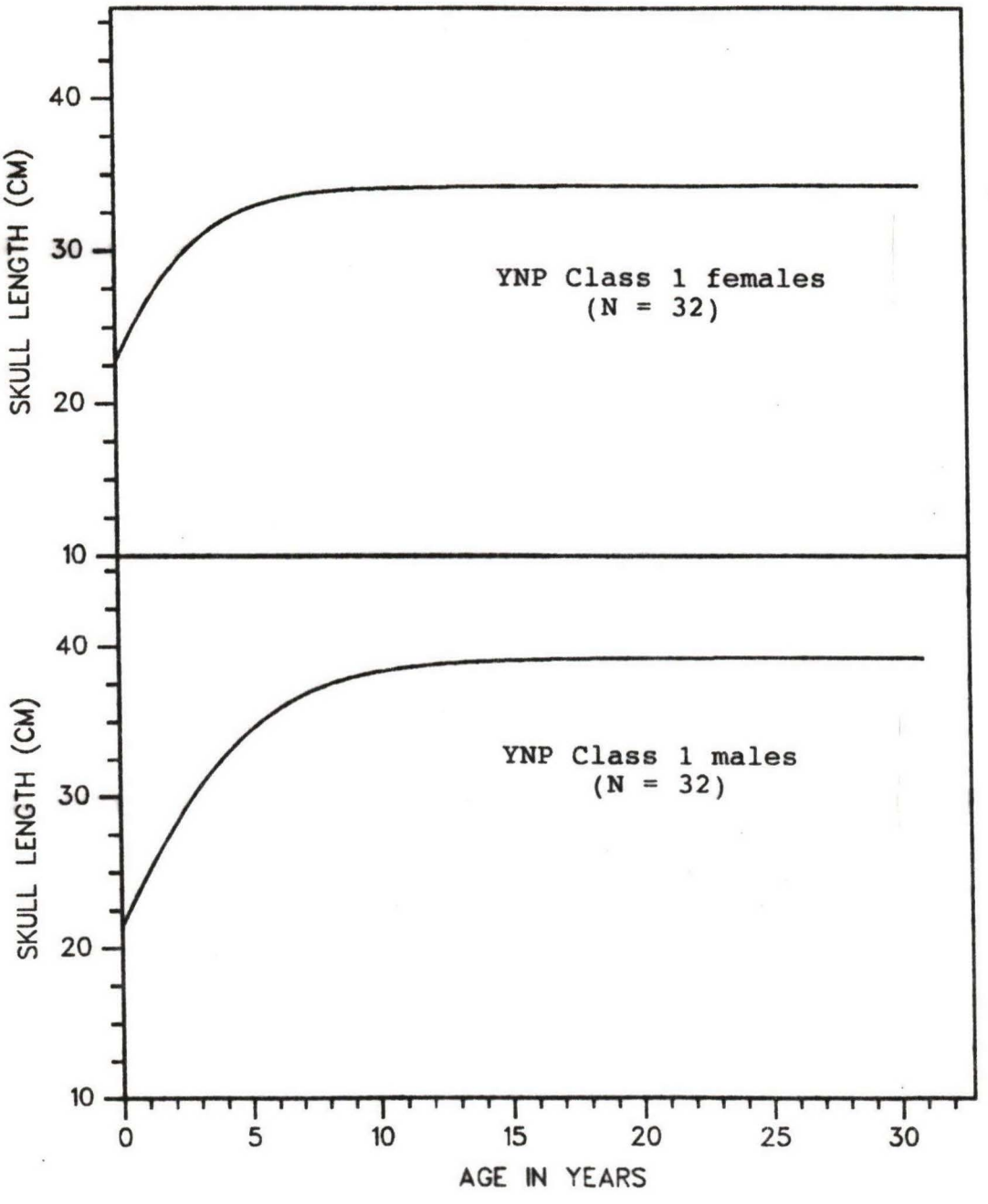

Figure 18. Growth in skull length by age for YNP grizzlies with open access to the dumps through maturity (class 1).

To determine the impact of the dump closures on skull growth in the YNP population, the YNP population was separated into 4 "classes".

These are shown in Figure 19 and defined on the basis of their access to the dumps either until maturity (age 11 for males, 7 for females) or death if prior to maturity.

YNP class 1 bears are those that had full access to the dumps through maturity or until their death if immature. There are 32 males and 32 females in this class (figure 19).

YNP class 2 bears are those that had full access to dumps for over 1/2 their growth period but not until they were fully mature. This would mean access for at least the first 6 years of life to a maximum of age 10 for males, and access for a minimum of 4 years to a maximum of 6 years for females. There are 7 females and 11 males in this class (Figure 19).

YNP class 3 bears are those that had access to the dumps up to a maximum of 1/2 their growing period (or death if prior to this date). For females, this would mean access for a maximum of 3 1/2 years after birth for males it would mean a maximum of 5 1/2 years access after birth. There are 9 females and 12 males in this class (Figure 19).

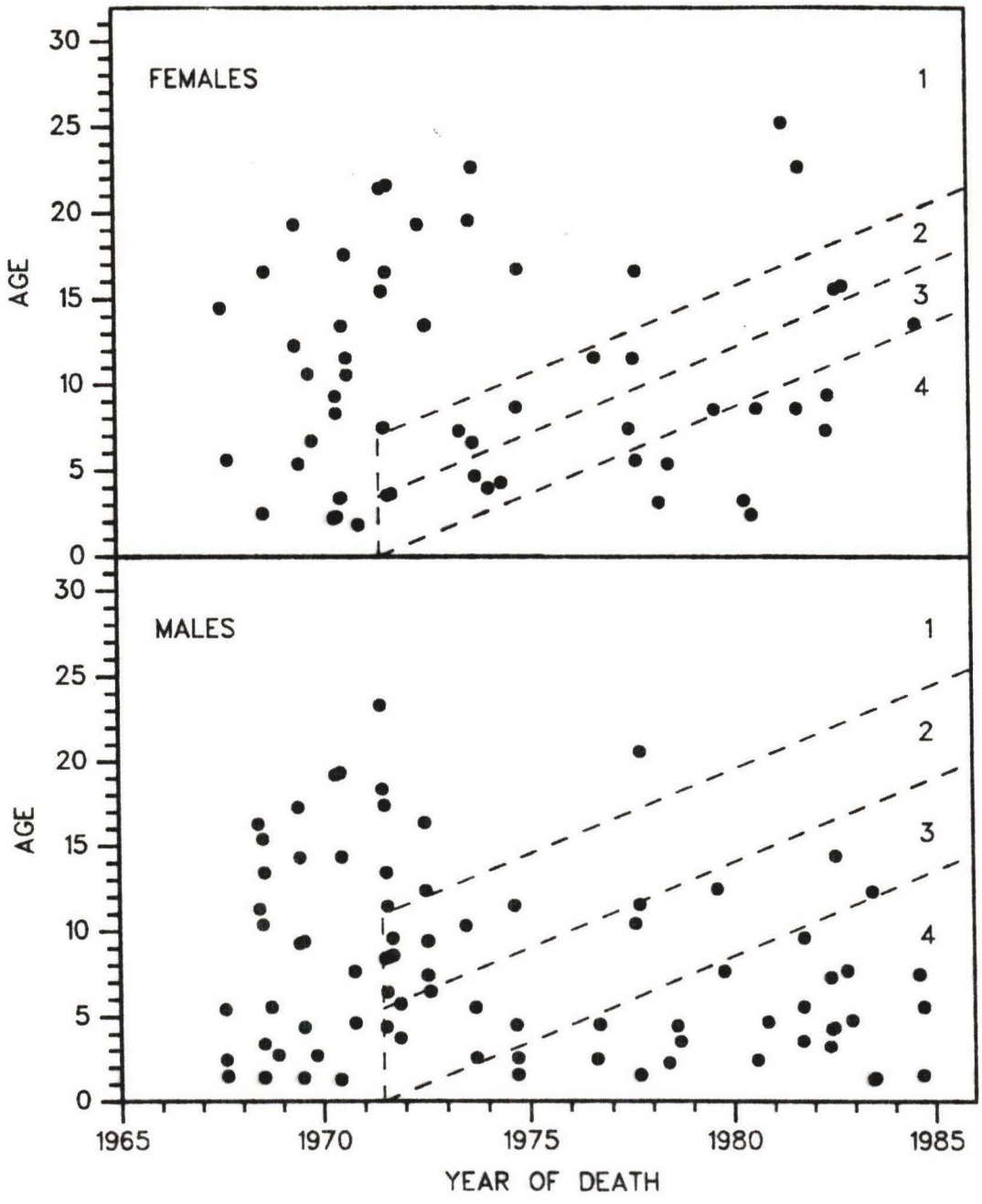

Figure 19. The age and time dependent accessibility to the YNP dumps by grizzlies. Class 1 bears would have had access to dumps their entire life, class 2 bears would have had access for over 1/2 their growth period but not until maturity, class 3 bears had access to dumps for up to a maximum of 1/2 their growth period, and class 4 bears had no access to the park dumps.

YNP class 4 bears are those that were born after dumps were closed and therefore had no opportunity to utilize this food source. There are 9 females and 25 males in this class (Figure 19).

The age spans in this classification differ from those used in the preliminary study (Figure 15) due to the expanded data showing that maturity is reached later for both males and females than previously assumed and that males grow for 4 years longer than females (11 yrs. vs. 7).

The above classification system allows comparisons of skeletal growth to be made between YNP grizzlies with unlimited access to park dumps (class 1) to YNP bears with limited or no access to the dumps.

For example, when YNP males that had either no access or were limited in access to 1/'2 their growth span (ages 1 -> 5 1/2) are plotted on the skull growth curve for males with unlimited access they fall well below the unlimited access males (Figure 20).

Similar growth curves plotted for YNP females show even greater skeletal growth reductions, with all bears with limited dump access falling below the unlimited access growth curve (Figure 21).

Comparisons of YNP bears with differing dump access to NMT skeletal growth models derived from skull measurements also

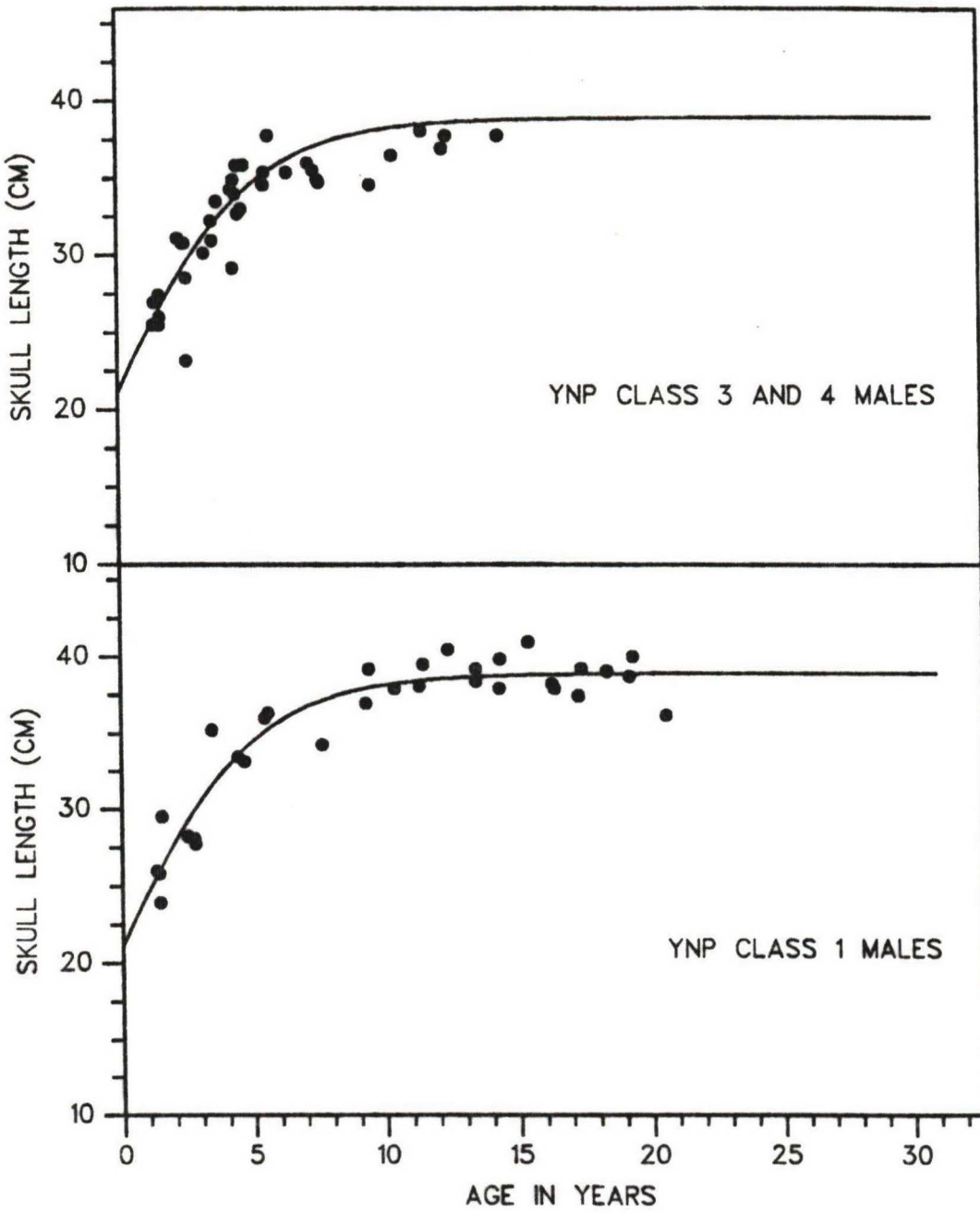

Figure 20. Skull growth by age for male grizzlies in YNP. The lower graph shows the growth pattern for bears with full access to the dumps through maturity or until death. The upper graph shows class 3 & 4 bears (no access or access limited to a maximum of 1/2 their growth period) plotted on the class 1 (unlimited access) growth model.

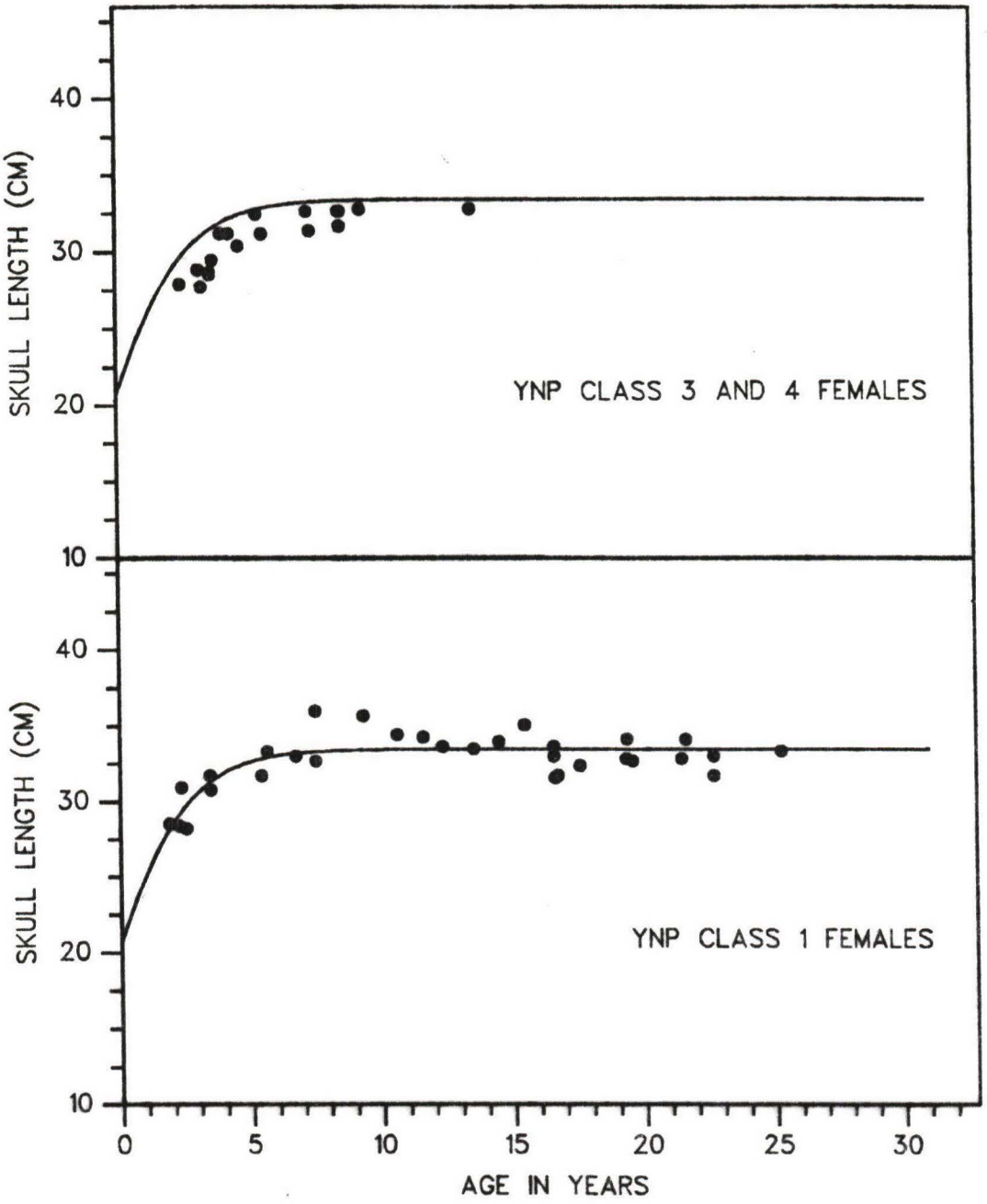

Figure 21. Skull growth by age for female grizzlies in YNP the lower graph shows the growth pattern for bears with full access to park dumps through maturity or death. The upper graph show class 3 & 4 bears (no access or access limited to a maximum of 1/2 their growth period) plotted on the class 1 (unlimited access) growth model.

reveal interesting trends.

When YNP males with unlimited dump access are plotted on the NMT skeletal growth model, they fall significantly above the line. The difference is especially noticeable in mature males (ages 11 and older) who lived long enough to have access throughout their entire growth period (Figure 22).

The same trend is apparent in YNP females. YNP females who had full access to the dumps throughout their growth period are significantly larger than their NMT counterparts (Figure 23).

However, when YNP females born after the dumps closed or those who had dump access for a maximum of 1/2 their growth period are plotted on the NMT female skeletal growth model they fall much closer to the NMT growth curve (Figure 23).

In summary, this study has shown that the added nutrition that was available to YNP grizzlies during the years the dumps were open resulted in significant increases in skeletal growth in both sexes. Bears living in the Yellowstone area during this time were significantly larger than their Northern Montana counterparts.

Once the dumps closed a significant reduction in skeletal growth in YNP grizzlies occurred. The increases in skeletal growth formerly shown by YNP bears of both sexes over Northern MOntana grizzlies has been greatly reduced and it appears that growth curves for the two populations will eventually show little or no difference.

It would be extremely useful if data from grizzly carcasses collected since 1985 could be added to our study. This would add

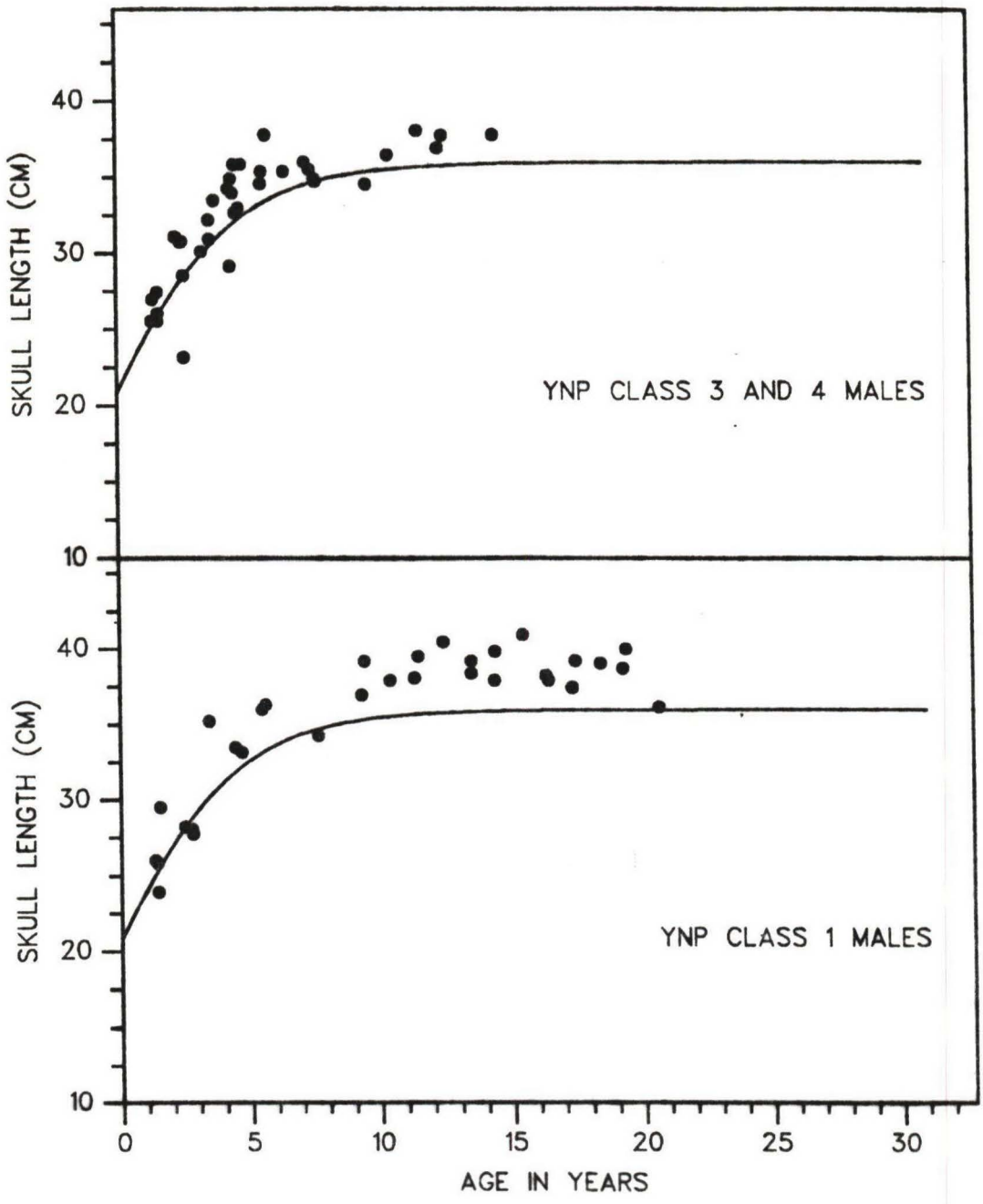

Figure 22. Skull growth by age for 3 classes of YNP male grizzlies plotted on skull growth models of NMT male grizzlies. The lower shows YNP males with unlimited dump access through maturity plotted on the NMT male model, the upper show YNP males with no or limited dump access plotted on the NMT male model.

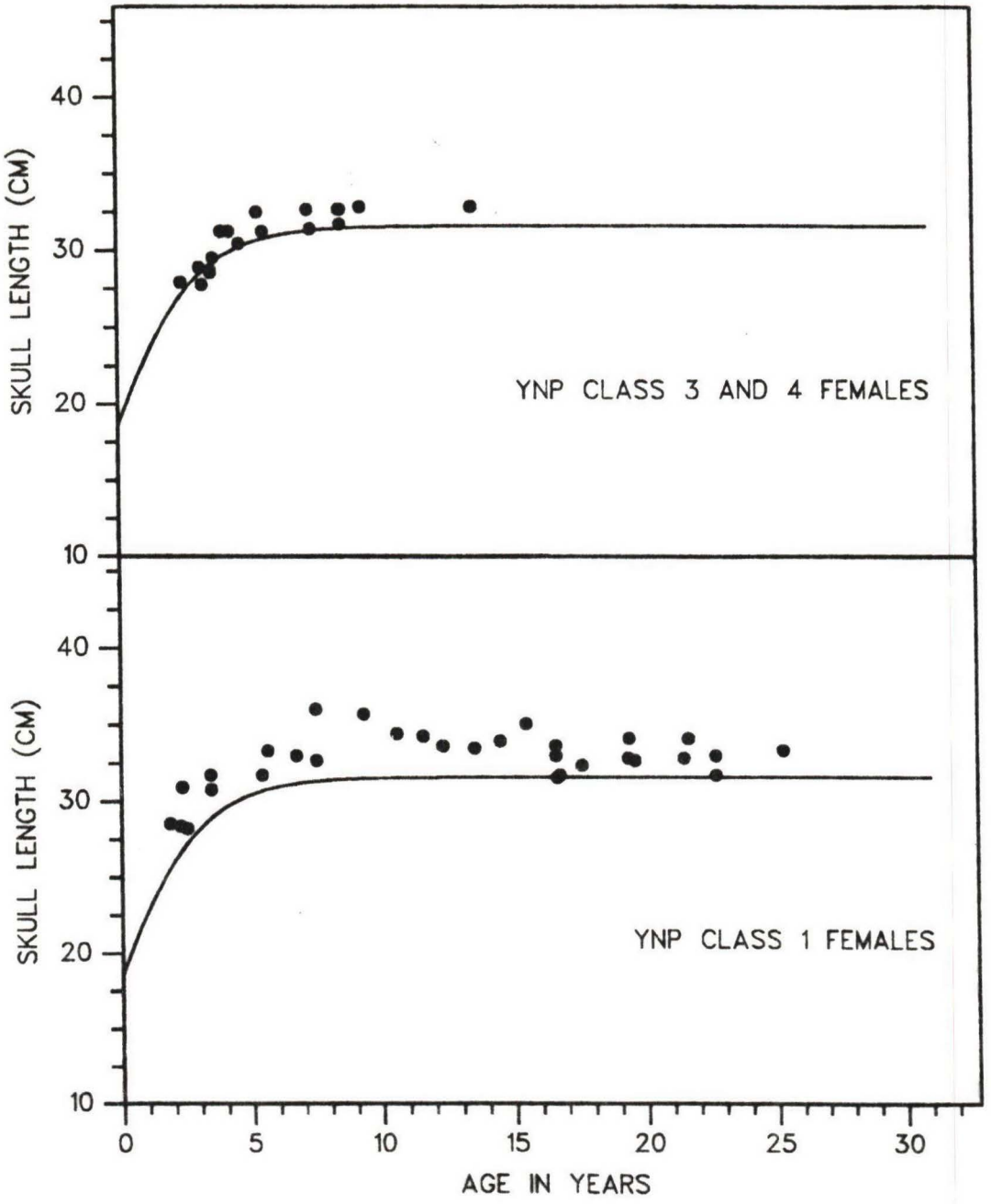

Figure 23. Skull growth by age for YNP female grizzlies plotted on skull growth models of NMT female grizzlies. The lower show YNP females with unlimited dump access through maturity plotted on the NMT female model, the upper shows YNP females with no or limited dump access plotted on the NMT female model.

a large number of Yellowstone area bears of older ages which have not had access or had only limited access to the dumps to our data.

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